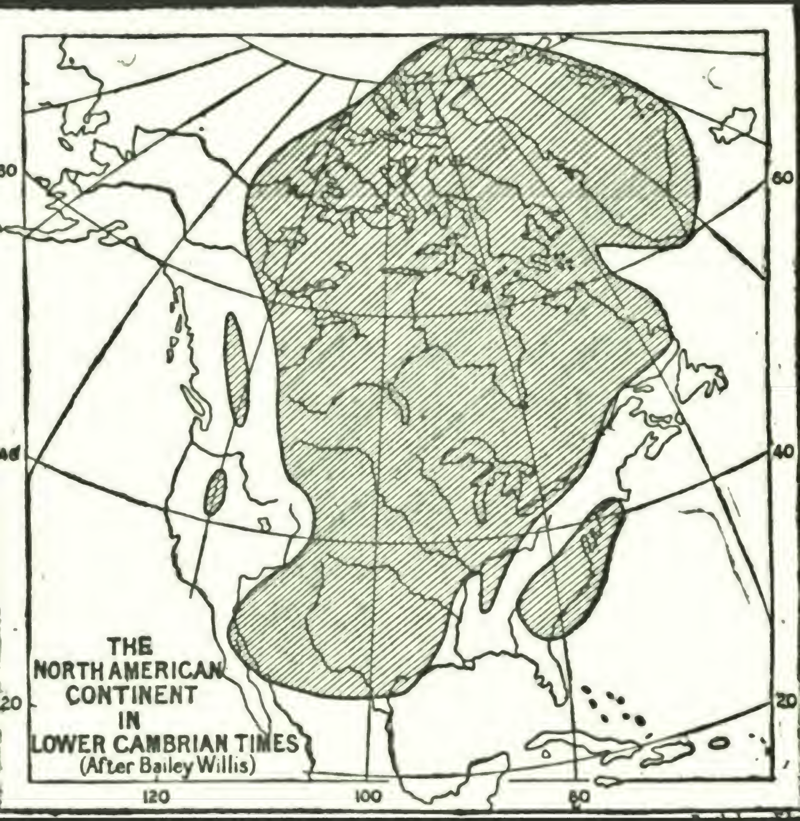
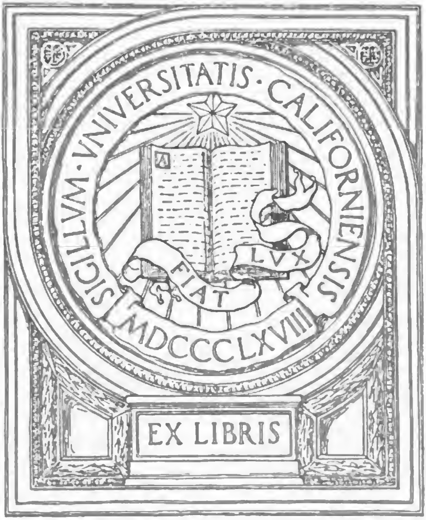


The making of the earth

John Walter Gregory

IN MEMORIAM
John Galen Howard
1864-1931



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THE MAKING OF THE EARTH

BY

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* Figures 13–17 are after Bartholomew's Zoölogical Atlas.

THE MAKING OF THE EARTH

PART I

THE ORIGIN OF THE EARTH

CHAPTER I

INTRODUCTION

THE making of the earth has always been an attractive problem to thoughtful minds. The simple solution of the writer of Ecclesiastes that "the earth abideth for ever" had been rejected by earlier thinkers as is shown by the inquiry in Job—"Where wast thou when I laid the foundations of the earth?" The cosmographers of the Middle Ages sought for a better answer, though, as their eyes were blinded by formulæ, they could only "darken counsel by words without knowledge"; it was not until recent times that men inspired by scientific imagination

and illuminated by the penetrative insight of modern instruments have discovered for this subject a firm, though still incomplete, foundation of fact.

The origin of the earth deals with events of primeval antiquity and with conditions very different from those of the present time. Hence it is not surprising that we find the problem attended by many uncertainties, for we only know the earth after it has waxed old and we only look upon the earth's cold outer surface. Of one fact we can, however, be sure; the earth was originally part of a much larger and less compact mass, from which came all the other members of the Solar System.

The earth is not unique in structure or material. Many of the heavenly bodies that we see in the sky at night are similar to the earth; for the spectroscope shows that some of them are composed of similar materials; some also of the fragments of shooting stars that fall upon the earth consist of the same minerals as the rocks of the earth's crust. That the earth and the other members of the

Solar System consist of similar materials, though not necessarily in the same proportions, follows from their origin as fragments of a formerly continuous mass.

The Solar System consists of its central body, the sun, and of a series of smaller bodies which revolve around the sun. The largest of these bodies are the eight major planets, which travel on regular and nearly circular paths known as their orbits. The planets are attended by moons which revolve around them. There are also many smaller bodies, the minor planets or planetoids, of which over five hundred have been seen; they range in size from twenty to four hundred miles in diameter, and in addition there are probably many others which are so small that they have not yet been seen. Still smaller than the minor planets are the bodies which are called planetesimals, as they are infinitesimally small planets. There are also countless meteorites which travel around the sun either singly or in swarms, and the comets whose orbits are oval-shaped or irregular.

The planets and their moons, the minor

planets, the planetesimals (or planetismals) and many meteorites were doubtless originally all parts of one vast body, which was spread out loosely over the space now occupied by the Solar System. Each member of that system has been formed by the concentration into small compact bodies of parts of this

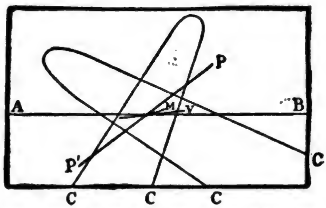


FIG. 1.—Diagram showing that the relations of the orbits of the planets will be nearly on the same plane. The orbits of the six larger planets are in the plane AB; the orbits of Mercury (M) and Venus (V) are slightly inclined to that plane; PP′ represents the most oblique of the orbits of the minor planets. The orbits of the comets (C) are inclined at all angles.

great cloud-like mass. This conclusion follows inevitably from two striking facts concerning the movements of the members of the Solar System. First, the planets all move around the sun nearly in one plane (Fig. 1); some of the minor planets such as Pallas rise and fall much above this plane,

and so also do the comets, but their orbits may have been altered from their original positions. Second, the eight major and the five hundred minor planets all move around the sun in the same direction, and with a few exceptions the moons revolve around their planets in the same direction.

The movements of the members of the Solar System may be illustrated by reference to a Catherine wheel or to a mop. As a Catherine wheel spins upon its axis it throws out sparks which keep in the same plane as the wheel and instead of going straight outward, travel forward in the same direction as the wheel is rotating; and if these sparks could be seen to rotate they would be found to go around in the same direction as the wheel. A wet mop furnishes a better illustration. When the mop is at rest its head is nearly spherical. If it be spun swiftly the shape becomes flattened like a disc thick in the middle and thinner towards the edge, and the water in the mop is thrown off as drops which keep in the plane of the flattened mop head. If the mop be wet with greasy water and it be spun

horizontally over a smooth surface then the drops thrown off may be seen to fly outward and also to move forward in the same direction as the movement of the mop, and each drop will spin in the same direction. Similarly if the major and minor planets and planetesimals were all formed from a vast loose body which was spinning around its centre, they should all move forward in the same direction, and unless disturbed by later influences should all revolve in the same plane.

It has indeed been estimated that the odds against this uniformity of movement being due to any other cause than that all these bodies were once part of one body which was spinning around its centre are many billions of billions of billions to one. It is therefore practically certain that the earth is a fragment of a once much larger and looser mass; but as to the nature of that body opinion is still divided.

CHAPTER II

THE NEBULAR ORIGIN

BEFORE the material of the Solar System was collected into compact bodies, it was widely spread out and existed as a nebula. "Nebula" is the Latin word for fog, mist, or vapour, or a slight thickening of the air,

FIG. 2.—Diagram showing the position of the Great Nebula of Orion (N) in relation to the Belt of Orion—the three stars in line (A).

and the nebulæ are cloud-like luminous patches sometimes appearing like wreaths of smoke. Most of them are so faint that they cannot be seen by the naked eye, and many can only be recognized by the aid of photography, even when their position is viewed through the most powerful telescopes. Two

of the nebulæ may be easily seen on clear starlight nights. The most easily found is the little hazy patch of light around the

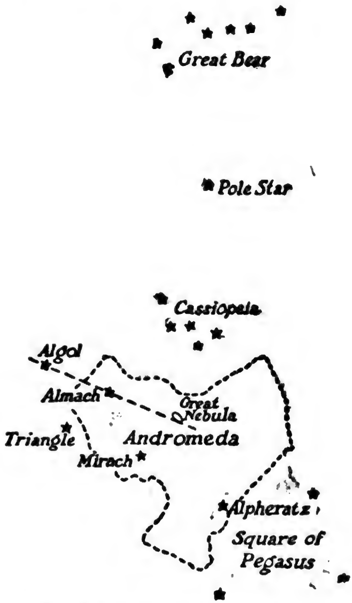


FIG. 3.—Position of the Great Nebula in Andromeda.

middle star in the Sword of Orion, which is the curved line of three stars hanging below the line of the three brilliant stars known as

Orion's Belt. The nebula in Andromeda (N in Fig. 2) is easily discerned by the naked eye (Fig. 3).[1]

The nebulæ are so numerous that the most powerful modern telescopes render visible about half a million; and they are divided into different varieties. Some are ring-shaped; others, known as the planetary nebulæ, have a small broad disc surrounded by a faint nebulous aureole; others, like the great nebula in Orion are quite irregular in shape. Another group have a spiral structure; the discovery of these nebulæ was perhaps the most important contribution to knowledge made by means of Lord Rosse's great telescope. These spiral nebulæ look as if they were rotating with the centre moving more quickly than the outer parts, which lag behind in curved lines like wreaths of smoke bent by a gentle breeze. The nebulæ are not equally compact throughout; they include bright spots or knots of a denser structure than the rest. These knots probably

[1] A popular account of the Great Nebula in Andromeda has been given by Gore in *Knowledge*, 1908, pp. 71–74.

represent the centres which ultimately grow into planets, while the glowing central mass, which is usually present, forms the sun.

The telescope therefore shows that some of the nebulæ are in a stage through which the Solar System passed long ago. The Solar System was probably formed by the condensation of the material of a nebula, the outer parts having contracted into planets, and the inner mass into the sun.

The nature of the nebula from which the earth has been derived is uncertain. The examination of the nebulæ by Lord Rosse's telescope showed that many of them were only "star clusters," in which the stars appear so close together that their light merges into a common beam. Several gas lamps in a group may appear from a distance as if they were all one; but on a nearer view the separate lights become visible. In the same way many of the nebulæ were shown by Lord Rosse's telescope to be merely groups of stars, and at one time it was expected that all the nebulæ would prove to be of this nature. The spectroscopic study of nebulæ

by Sir William Huggins showed, however, that, in addition to the nebulous-looking star clusters, there are nebulæ of very different composition. They are generally regarded as composed of gas. According to that interpretation these nebulæ have the structure assigned to nebulæ in general by the distinguished French astronomer Laplace in 1796. He regarded each nebula as a cloud of gas so intensely hot that it is incandescent; and according to Laplace's theory this glowing mass is spinning around its centre, and as it cools it breaks up into separate rings, from which are formed the different members of a stellar system.

Subsequent observations on the nebulæ discovered several facts which were in accordance with Laplace's theory. Thus photographs taken by modern telescopes show nebulæ in the various stages assumed by the nebular hypothesis. Thus the photograph taken in 1887 by the late Dr. Isaac Roberts of the great nebula in Andromeda shows that it is disc-like in form, that it has a large glowing central mass, and that the less lumi-

nous outer portion is breaking up into rings; and where we can look through the outer portion of these rings, they appear to be breaking up into patches, which may be the beginnings of future planets.

The same appearance is seen in a photograph taken by Dr. Roberts of the spiral nebula in the constellation of the Hunting Dogs. This nebula presents to our view the surface of its disc instead of the edge as with the nebula in Andromeda. We can therefore see that it consists of a number of curved spokes radiating from a central mass; and these spokes contain many brighter specks or knots which may be regarded as embryonic planets.

Hence the telescope shows that some of the nebulæ are divided into rings, as Laplace assumed they would be, and that some have a spiral plan indicating their rotation around the centre. The rotation is apparently slower than Laplace would have expected. Thus the spiral curvature of the rays appears to be due to the lagging of their outer ends; and if so, the rotation must be slow; and com-

parison with the photograph of the great nebula in Andromeda suggests that the rotation, if any, is imperceptible. An instructive drawing of the nebula was published by G. P. Bond[1] in 1848, and the features in his sketch which can be identified occupy the same relative positions as in the later figures, and therefore do not indicate any rotation of the nebula. A more reliable comparison can be made between the photographs taken by Isaac Roberts on October 10, 1887, and by Ritchey at the Yerkes Observatory in September 1901. The chief knots in the nebula can be recognized in both photographs.

If the nebula were revolving the movement should be most obvious on the extreme borders of the disc and the movement should be recognized by some change in position of the edge of the knots in relation to the adjacent stars. The knots are somewhat larger in Ritchey's photograph owing to the superior power of his instrument; but the knots occupy precisely the same position in reference to

[1] "An Account of the Nebula in Andromeda," *Memoirs of the American Academy of Arts and Sciences.* New Series, vol. iii, 1848, pp. 75–86.

the stars seen through the nebula as they did in 1887. Thus the knots shown in the lower left-hand side of Dr. Roberts' photograph and the three knots on the upper border are seen in both photographs. The right-hand knot of the three is bordered below by a black rift which appears to be in precisely the same position in both photographs. Along the lower edge of this knot is a line of three small stars; the outer margin of the central star just touches the rift; the left-hand star is partly in the nebula and partly in the rift. It would appear therefore that the rotation of this nebula must be so slow that it has not produced the slightest perceptible movement of even its outer edge during fourteen years.[1] The aspect of the nebula suggests that the knots may be due to some process of segregation in a comparatively stagnant mass rather than to the action of gravity in a rapidly rotating mass.

The support to Laplace's theory given by the telescope has been supplemented by that

[1] The claim in respect to one nebula, that its rotation had been recognised, has been disproved by Professor H. H. Turner, *Mem. Not. R. Astr. Soc.*, vol. lx, pp. 530–531.

of the spectroscope. This instrument contains one or more triangular bars of glass which break up a ray of white light into its different component colours. The action of the instrument may be illustrated by the effect of a "lustre," or triangular bar of glass from an old-fashioned chandelier, upon a ray of light passing through a small hole in a sheet of cardboard held before a lamp. The spot of white light when seen through this triangular "prism" of glass is drawn out into a band and this band ranges in colour from violet at one end to red at the other. This band of coloured light is known as a spectrum.

There are three kinds of spectrum. A "continuous spectrum" is one which is one unbroken band from blue to red, and this kind of spectrum is given by incandescent solids, liquids or dense gases. They each give a continuous band of light, in which the seven colours shown on Fig. 4*a* pass gradually into one another. The spectrum given by a rarefied incandescent gas consists only of a series of bright lines situated at different parts of the spectrum (Fig. 4*b*); and each

chemical element has a characteristic line or series of lines. Hence by mapping the bright lines in a spectrum, the chemical composition of the source of the light can be determined.

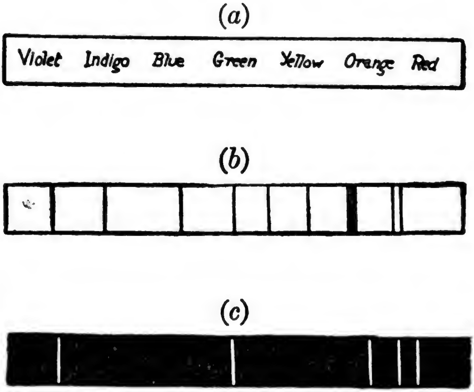


FIG. 4.—The three kinds of Spectra.

(a) Continuous Spectrum.
(b) Bright-line Spectrum of the Great Nebula in Orion (after Huggins).
(c) Dark-line, or Absorption Spectrum.

A third type of spectrum is the dark-line spectrum, in which the colour band is broken by a series of dark lines as in Fig. 4*c*. This dark-line spectrum is formed when light from a bright body passes through a material which

absorbs some of the light; and this absorption produces dark bands at the precise positions where the incandescent vapour of that material would give bright lines.

The sun, for example, gives a dark-line spectrum, for it consists of a hot central mass which would be sufficiently dense to give a continuous spectrum; but the light from the central mass passes through an outer layer which absorbs some of it, and the continuous spectrum is altered into a dark-line spectrum; and the dark lines present demonstrate the chemical composition of the sun's outer layer. Some of the stars such as Capella are shown by their spectra to have the same composition as our sun.

The application of the spectroscope to the nebulæ is attended by great difficulty owing to the extreme faintness of their light. The late Sir William Huggins, however, in 1864 first observed the spectrum of a nebula and recognised that it was a bright-line spectrum. It was therefore naturally concluded that such nebulæ are composed of incandescent gas, as required by Laplace's theory. Sir

William Huggins showed that the nebulæ apparently consist of three constituents, nebulium, an element otherwise unknown, hydrogen and the rare gas helium.

Further studies of the spectra of nebulæ have shown that they may be divided into two groups. The members of the first group all appear to have a continuous spectrum visible as a very faint background, upon which stand out the bright lines of the three above-mentioned elements. These lines have been recognized in over one hundred nebulæ, including the ring-shaped and planetary varieties and in some irregular forms such as the great nebula of Orion. Such nebulæ are therefore regarded as composed of incandescent gas.

The other group of nebulæ have a dark-line spectrum, and are therefore spectroscopically similar to such stars as the sun; they are regarded as spectroscopically indistinguishable from star clusters, though composed of different materials from those in the sun and in ordinary stars. This group includes by far the great majority of nebulæ,

including the great nebula of Andromeda and all the other spiral nebulæ. "A spiral nebula," says Sir Robert Ball, "is not gaseous." Their spectra appear to be almost continuous, as they are crossed by very few absorption lines. Hence the spectroscope appears to indicate that most nebulæ have an outer zone which is colder than the central mass, and their structure in that respect agrees with that of the sun and of ordinary stars. The nebulæ with a bright-line spectrum on a fainter continuous spectrum would appear to be surrounded by an envelope of intensely hot gas; and when this gas has cooled down it might produce the dark-line spectrum of the ordinary nebulæ.

Even in regard to nebulæ with bright-line spectra, astronomers are not agreed that they are necessarily gaseous. The late E. J. Stone, the Radcliffe Observer of Oxford, claimed in 1877, that even such nebulæ might be star clusters surrounded by a continuous zone of gas; for he held that if these star clusters were at sufficient distances from the earth, the light from their gaseous envelope would

predominate over that from the stars within and thus give a bright-line spectrum.[1]

The nebulæ which give a bright-line spectrum are, however, usually regarded as composed of incandescent gas; and they may pass by cooling into nebulæ composed of luminous solid materials surrounded by a darker atmosphere.

The great difficulty in the nebular hypothesis is to understand how material so extremely diffuse as the gas of a nebula—and its density was estimated by Lord Kelvin as one-millionth of that of ordinary air—could remain incandescent for a long time through its own heat. The heat would be so rapidly lost by radiation that the gas would soon be chilled.

How quickly incandescent material cools is shown by the short life of new stars, which every now and then startle astronomers by their sudden appearance. Thus Professor Pickering of Harvard, in February 1901, photographed part of the constellation of Perseus; a few days later a new star suddenly

[1] *Proc. R. Soc.*, vol. xxvi, 1877, pp. 156, 157, 517–519.

appeared in this very part of the heavens. It rapidly increased in brightness until it became one of the most brilliant stars in the sky. It was first observed on February 22, 1901. Its spectrum a week later showed the bright lines which indicate the presence of incandescent gas. The star was clearly the result of an explosion, which led to the flaring up of a formerly invisible body and to the outrush from it of large quantities of incandescent gas. The star, however, soon waned in brightness. It occasionally increased in brilliancy owing to a fresh flicker of activity; but within a few weeks it had ceased to be recognisable by the naked eye. This phenomenon may have been caused by a collision between two cold dead stars; and as would be expected, the gas and fine materials rendered white hot by such a collision soon cooled and thus again became invisible.

The difficulty in explaining the prolonged luminosity of the nebular material is overcome by the meteoritic hypothesis of Sir Norman Lockyer, which has been extended

and developed by Professor T. C. Chamberlin of Chicago in an especially attractive form. According to this theory a nebula consists not of incandescent gas but of a vast swarm of those solid meteorites which can be seen on a cloudless night as shooting stars flashing at intervals across the sky. These meteorites are usually cold and dark; when they enter the earth's atmosphere they are heated by the friction and are reduced to powder, which can be seen for a moment as a trail of incandescent dust. The members of a meteoritic swarm are assumed on the meteoritic theory to be heated by continual collisions; and the heat due to the collisions is thought to convert parts of the meteorites into hot vapour. This is soon condensed, but more is formed by further collisions. Hence according to the meteoritic hypothesis the nebulæ, instead of being diffused clouds of intensely heated gas, are swarms of solid meteorites, which were originally cold but are heated by collisions and thus give off a continuous supply of incandescent vapour.

The meteoritic theory was first advanced

by Tait of Edinburgh in 1879 to explain the nature of comets. He suggested that a comet is a swarm of meteorites of which the members vary in size from that of a marble to boulders twenty or thirty feet in diameter. As the swarm travels along its path the separate stones come into constant collision; they thus become white hot on the surface and surrounded by incandescent vapour due to part of the meteorite being volatilised. Professor Tait calculated that in an ordinary comet the number of stones would be so enormous that there would be sufficient to maintain the life of a comet for millions of years even at the rate of a million collisions every second. He concluded that the luminosity of a comet could be satisfactorily explained as due to collisions between its component meteorites.

This explanation of the light of comets is not generally accepted, but Tait's theory is of great historic interest as one of the steps toward the theory of the meteoritic structure of the heavenly bodies.

Sir Norman Lockyer in 1890, after a de-

tailed investigation of the spectroscopic evidence then available, advanced the hypothesis that the great star systems themselves are composed of swarms of meteorites. He pictured the universe as traversed by innumerable meteorites, which he represented as being so crowded in some places that he described these areas as "meteoritic plena." A "plenum" is a space filled with matter in contra-distinction to a vacuum. The parts of space occupied by these meteoritic plena have according to Sir Norman Lockyer condensed into various solar systems.

The chief difficulty in the meteoritic theory is that due to the chemical composition of the meteorites. The meteorites are unquestionably solid bodies, and as they pass through space they are so intensely cold that it sometimes takes hours after they have fallen on to the earth before they are sufficiently warm to be handled. Some of these meteorites are immigrants into the Solar System from outer space. Many of them, on the other hand, are members of that system and travel in regular orbits around the sun;

and these meteorites have been named by Professor Chamberlin planetesimals as they are infinitesimal planets. Their orbits, however, often differ from those of the planets, as many of them plunge like comets to and fro across the plane to which the planets are confined. The meteorites are seen as meteors or shooting stars when they rush like rockets across the sky at night. They are invisible until they enter the earth's atmosphere, where, as they dash through it at the rate of from eight miles to seventy miles a second, they are warmed by the friction, and glow with incandescent light. They exist in such myriads that it is estimated that from eight to ten can be seen by an observer within an hour on any clear moonless night. It is calculated that twenty millions of them large enough to be seen by the naked eye enter the earth's atmosphere every day, and Sir Norman Lockyer estimates that the total number which reach the earth may be 400,000,000 a day. Most of them are extremely minute, and they vary from the size of shot or peas to blocks weighing a few thousand pounds.

Their average size is, however, so small, that it has been estimated that they only add to the earth a layer $\frac{1}{1000}$ of an inch in thickness in a million years.

The composition of meteorites is known, since fragments are often found on the surface of the earth. Several have been seen to fall; a man in India was killed by one and various other fatalities have been narrowly escaped.[1] The meteorites are of two main types. The commonest and the largest consist of lumps of metallic iron hardened with from six to ten per cent. of nickel. They also contain many earthy minerals of the kinds rich in iron and magnesia and poor in silica.

The meteorites of the second group consist of the earthy minerals which form the rocks known as basic (see p. 64). Their mineral constituents include olivine, the basic felspars and chromite. They have never been found to contain quartz or the acid felspars.

Many of the meteorites contain gases of

[1] It has been recently reported that on January 25, 1912, the signalling apparatus at Lloyd's station at Finisterre, in north-western France, was destroyed by the fall of a meteorite.

which the most important are carbon dioxide, carbon monoxide and hydrogen. In some of them, nitrogen is an important constituent. The great Cranbourne meteorite which fell in Victoria, Australia, yielded gas containing seventeen per cent. of nitrogen.

The constituents of the great majority of the meteorites occur in rounded grains, the shape of which has been attributed to friction; sometimes they are made up of angular fragments, as if the meteorite had been broken up and the pieces again pressed together. The meteorites with rounded grains (chondrites) have been regarded as due to the fusion of many separate granules into a large mass.

Thus according to Arrhenius these meteorites are due to rounded grains discharged from the sun being collected into compact solid bodies. According to Dr. Fletcher, one of the leading authorities on meteorites, these structural features may, however, be explained as due to hurried crystallisation.

No meteorites composed of acid rocks have yet been found: their absence may be explained by the fact that the typical minerals

of these rocks are only formed in the presence of intensely heated water. Some nodules of obsidian which are widely scattered in Australia have been regarded as meteorites by many authorities, but their microscopic and other characters indicate that they may be formed by the fusion of dust by electric discharges in the earth's atmosphere, and may therefore have been formed as aerial fulgurites.

The composition of the meteorites is of extreme interest, because they give us the only chance we have of actually studying fragments of other heavenly bodies under the microscope or in hand specimens. They also reveal to us the chemical composition of comets, as there can be no doubt that the comets and meteorites are most intimately associated.

A comet consists of a small bright nucleus, which when near the sun throws out behind a long tail like a thin wreath of luminous smoke. Some of the comets travel around and around the sun. Others enter the Solar System from outside and, after dashing across

it, pass off again into outer space. That comets and meteorites are similar in composition is shown by the occasional change of a comet into a meteoritic swarm. Thus Biella's comet travelled around the sun and reappeared to view at intervals of 6.67 years from 1772 to 1852; on the last occasion it had broken into two, and at the date when it was next expected it was not seen; and its place was taken when it was next due by a swarm of meteorites. The comet had broken up into meteorites. In the same way Tempel's comet has been replaced by the great meteoritic shower called the Leonids, for the meteors appear in the constellation Leo or the Lion, and they are seen at intervals of about 33⅓ years. A meteorite that fell in the Tyrol in 1910 has been claimed as a fragment of Halley's comet.

There can therefore be little doubt that comets and meteorites must have the same composition. The most difficult problem in connection with comets is the source of their light, which was originally attributed, like that of nebulæ, to the glow of incandescent

gas. The difficulty of diffuse matter maintaining a white heat and the fact that comets' tails when passing near the sun travel far above the speed-limit theoretically possible for such material render this explanation improbable. The view is now generally accepted that the light of the comets' tails is an electric effect due to the influence of an emanation from the sun upon the particles in the tail. The question asked by Huggins in 1874, "Is the comet's light due to electricity in any form excited by the effect of the solar radiation upon the matter of the comet?"[1] has been answered in the affirmative. The light of the nebulæ is perhaps due to the same cause, though according to Sir William Huggins, "We can scarcely go wrong in attributing the light of nebulæ to the conversion of the gravitational energy of shrinkage into molecular motion."

There can be little doubt that comets and meteorites have the same composition, but there is one difficulty in the view of the

[1] "On the Spectrum of Coggia's Comet," *Proc. R. Soc.*, vol. xxiii, p. 159.

meteoritic composition of the nebulæ. The spectra of meteorites include the lines characteristic of iron, nickel, magnesium and carbon, and several carbon compounds are found in meteorites. The spectra given by nebulæ show none of these materials. The ordinary nebulæ with bright-line spectra show only the lines of the rarefied gases nebulium, hydrogen and helium. Some of the lines were at one time identified as those of magnesium, one of the elements most charactersitic of meteorites, but this identification has not been confirmed. Hence if we can trust the spectroscope, nebulæ are of different chemical composition from meteorites. This argument, however, does not seem to be conclusive; for although it is almost certain that comets and meteorites have the same composition, yet their spectra are strikingly different. The spectra of comets were first interpreted by Sir William Huggins, who found in the spectrum of the comet of 1881 two groups of bright lines; he showed that most comets have a continuous spectrum, which is due to the reflected light of the sun,

and also a bright-line spectrum due to gas. These bright lines are in two groups and prove the presence of hydrocarbons and sodium. The spectra of comets give no indication of the many metals that are no doubt present in them. It is, therefore, possible that if nebulæ be clusters of meteorites, their faint light may not reveal their meteoritic composition. The faint nebulosity which gives their bright-line spectrum may, as with comets, be due to an electric glow from the rarefied gases in the outer zones of their atmosphere.

The difference between the spectra of comets and meteorites renders the spectroscopic argument that nebulæ are not composed of meteorites unconvincing; and even those that give bright-line spectra are not necessarily composed of incandescent gas.

The difficulty in the theory that the earth has evolved from a meteoritic nebula is in explaining the collection of the scattered meteorites into compact swarms; for it is held that if the materials of the Solar Sys-

tem were regularly distributed over its whole area in small meteorites, there is no adequate cause for their collection into solid masses and for the intervening spaces having been left practically empty.

The formation of planets by the collection of meteorites into masses must depend, not on those which are flying haphazard through space, but on those which belong to the Solar System and are travelling in regular orbits; for the erratic meteorites are moving with such high velocity that the power of gravity would have a very slight influence upon them. Their great momentum would prevent them being seriously deflected by the attraction of other bodies as small as themselves, unless they came into very close proximity. Two cannon balls fired at the same time in the same direction from two guns a few yards apart are not appreciably deflected from their paths by attraction to one another.[1]

[1] The gaseous nebula theory is also open to the objection that the force of gravity would not collect the material thrown off as rings into planets. Other serious objections to that theory on mathematical grounds have been advanced by Professors Chamberlin and Moulton.

The view that the nebulæ have themselves been formed by the collection of erratic meteorites is attended by the difficulty that the meteorites must be very small in comparison with the space through which they pass. The amount of solid material in the spaces between the stars is apparently insignificant. If a little thin smoke, which even in the daytime would be invisible, drift overhead on a clear night it dims the stars, and a very faint cloud will obliterate them altogether. Hence the amount of matter in space must be insignificant, as it has a less effect than the thin bands of moisture in the atmosphere, The twinkling of the stars was once attributed to bodies coming between the earth and the stars, but it is now regarded as an atmospheric effect. In spite of the myriads of meteorites, their volume is as nothing in comparison with the immensity of space.

Professor Chamberlin therefore holds that the formation of planets in a contracting nebula must depend upon the planetesimals. The paths along which they travel are themselves slowly moving. Hence every plane-

tesimal traverses the orbits of others and thus has an excellent chance of being brought sufficiently close to another for the attraction of gravity to bring them together.

Thus slowly the meteoritic material would collect into knots and they would form planets which would consist of the same materials as the earth and would travel around the sun in the same plane and in the same direction.

The available evidence is therefore consistent with the hypothesis that the nebula from which the earth has been formed consisted of a swarm of meteorites; for some of the nebulæ show the continuous spectrum characteristic of incandescent solids or dense gases, and some authorities claim that the spectroscopic evidence proves that many nebulæ are composed of solid constituents. The more primitive stage of the nebulæ may be gaseous, as required by Laplace's theory; but these gaseous nebulæ appear to condense directly into scattered meteorites instead of throwing off rings of gas which collect into planets. The essential difference between the

two theories is, that according to Laplace's theory such bodies as the planets are formed by passing through a stage of gaseous rings, and according to the meteoritic theory by passing through a stage of small scattered solid bodies.

A sun and its attendant planets will by the slow contraction of their materials at length become so compact that no further contraction can take place, and that system will become cold and dead. It will travel through space as a cold dark star. If on its journey, it happen to collide with another cold star, the energy due to the collision would cause a sudden generation of heat and scatter the materials of both bodies with explosive violence. The collision would again convert the two cold stars into a nebula. If the two bodies met in a grazing collision the two central masses would not become completely welded into one; and both would rotate around their common centre. The materials hurled out by the explosion would give rise to radial arms, and as each half of the new body would start its own series of rays, the

collision, as Professor Chamberlin has suggested, would produce a nebula with two series of rays. Owing to the quicker rotation of the centre, the outer ends of the rays would bend backward and form a spiral nebula. In process of time the solid material in these rays would collect into knots; as the nebular system rotates these knots would move around the central sun and each would collect all the planetesimals along its path; and thus the material which was once widely scattered will be collected into planets like the earth.

The two armed spiral rays of the nebula have received a different explanation from Schaeberle in a letter "On the Origin of Spiral Nebulæ" (*Nature*, vol. lxix, 1904, pp. 248–250). He explains them as the result of explosion in a cooling rotating nebular mass. The explosion according to him would make holes in the crust on opposite sides of the nebula; and through the pair of vents the material of the nebula would be shot forth in long rays. The repetition of similar volcanic explosions, always in pairs of antipodal vents, would then produce a many-rayed nebula,

and the spiral arrangement of the rays would result from the rotation.

The energy due to the collision of the two suns will scatter their material. The central mass will be the hottest and its heat will be maintained by the slow concentration of the material. Then, when the central star of a stellar system has again become compact its planets would have become cold. But another collision with a similar body would restore the nebular condition, and the evolution of a solar system would again be started on its former round.

Worlds and meteorites may, however, be shattered without coming into direct collision by the process known as "Roche's effect" after the French mathematician who, in 1848, first called attention to its importance. Professor Chamberlin, who has used this process to explain some of the characters of meteorites, has appropriately described it as "disruptive approach." The nature of this effect is as follows:—The surface of the earth presses downward owing to the attraction of the underlying material. If another body

were placed above the earth at such a distance that its upward attraction would counterbalance the downward pull of the internal material, then the water confined within the earth would burst into steam and scatter the overlying strata by a violent explosion. The whole earth would be shattered by the shock, and the fragments hurled into space. Each separate piece, however cracked, would be recemented into a firm block by the cold of outer space, but would retain the broken and crushed aspect seen in many meteorites. Professor Chamberlin regards meteorites as fragments of larger bodies which have been torn asunder by this "disruptive approach" as they pass near one another and without actual collision.

CHAPTER III

THE EVIDENCE OF ANCIENT CLIMATES

THE foregoing consideration of the nebular theory involves subjects which belong to the domain of astronomy and on many of the problems the geologist has to accept the verdict of the astronomer. The geologist may, however, test the two theories of the earth's origin by determinimg whether the view that the earth began as a cloud of incandescent gas, or as a swarm of cold solid meteorites, agrees the better with the direct evidence from the history of the earth. If the earth were once a mass of incandescent gas some indications of the intense heat of its early period might be expected in its oldest rocks; and there should be evidence of a gradual cooling throughout geological time.

On the incandescent nebular theory we should expect that the oldest climate of which the geologist can discover records should have

been very hot. It may be suggested that the earth cooled so rapidly in its early stages that its surface soon reached approximately its present temperature. If, however, the central mass of the earth had the intense heat assumed by the theory of the incandescent nebula, this suggestion is improbable; for the crust of the earth transmits heat so slowly that the temperature of the interior should fall very slowly. A second explanation that may be offered is that all the rocks known to the geologist were formed in the period after the establishment of a comparatively stable climate, which varied between the existing extremes of heat and cold. If so the time occupied by the geological history of the earth is insignificant in comparison with the length of the period since its solidification; and this explanation is also very improbable.

The geologist may reasonably expect on the incandescent nebular hypothesis to find traces of a hot climate when the earth was young. It was at one time thought that there is such evidence; for in many places wide

tracts of granite appear from beneath other rocks. Granite is a rock that was clearly once molten and was formed in presence of great heat; and the wide sheets of it in the foundation rocks of the earth's crust were regarded as remnants of a world-wide shell of granite that was the first rock formed by the solidification of the molten globe. The granite was considered to be the remains of the first shell around a then molten interior. It has, however, been found that these granites and granitoid rocks are not the oldest rocks of the earth's crust. They can only be formed under great pressure beneath sheets of older rocks; and they have been forced upward into the overlying sedimentary rocks. The climate of the world in its earlier days must therefore be determined by what we can learn from the oldest sedimentary rocks.

The geologist divides the history of the earth into four great eras, just as the historian divides the history of mankind into four ages—the prehistoric, the ancient, the medieval and the modern. The geological

eras are named from the stage of the development of the animals and plants that inhabited the world during them. The first era includes the dawn of life on the earth, and its sole occupation by archaic forms of living beings; it is therefore known as the Eozoic or Archæozoic. The second era is that in which the earth was inhabited by animals and plants of ancient forms, and is therefore known as the Palæozoic—the era of ancient life. The third era is that during which the animals and plants that dwelt on the earth were intermediate between the ancient and modern types; it is therefore known as the Mesozoic—the middle era of life. The last era, that in which we are still living, is the Kainozoic or era of modern life.

Each of these eras are subdivided into periods, the names of which are given in the following table—

Geological Eras.	*Periods.*
	16 Pleistocene
	15 Pliocene
4 Kainozoic . .	14 Miocene
	13 Oligocene
	12 Eocene

3 Mesozoic . .	11 Cretaceous 10 Jurassic 9 Triassic
2 Palæozoic . .	8 Permian 7 Carboniferous 6 Devonian 5 Silurian 4 Ordovician 3 Cambrian
1 Archæozoic or Eozoic . .	2 Torridonian (British) 1 Archean

The rocks deposited in an "Era" together form a geological Group, and those deposited in a "Period" form a geological System.

We can judge the climate of any period or locality by the animals and plants that lived in it. Thus coral reefs now grow only in the warm seas of the Tropics; and when we find the remains of ancient coral reefs in any part of the world we may reasonably conclude that the sea in which they were formed was then tropical or sub-tropical. Some English limestones are so crowded with corals that they may be fairly called coral reefs; we may infer that they were formed in warmer water than any met with in British

seas at the present time. There are no coral reefs in the British area in the oldest systems, but limestones which have been regarded as such were formed in our seas during the fifth, sixth, seventh and tenth periods in the preceding list; and this distribution gives no evidence of any steady cooling of the British climate.

The strength of the physical forces that deposit rocks also indicates the conditions of the climate during their formation. The winds are due to differences in temperature between various parts of the earth. Thus a strong wind is formed where a large tract of hot land is situated near a colder sea. The wind is a delicate gauge indicating differences in heat and cold between neighbouring areas. If there had been much greater differences in the distribution of temperature on the earth in past times, we should expect that the winds would have been much stronger.

The oldest rocks in the British Isles are in the north-western Highlands of Scotland; and among them, beside Loch Assynt in

Sutherland, is perhaps the most ancient land surface that has been preserved upon the earth. Some primeval hills and valleys were buried beneath sand which has been converted into sandstone; and thus they have endured throughout nearly the whole length of geological time, until now the gradual removal of the overlying sandstone is again exposing the ancient surface. The sand was blown across this old land by the wind, and many of the pebbles were shaped by the drifting sand. The sand grains are of the same size as those that are blown along by the winds of the present time, and the prevalent wind in that locality blew from the south-west in Archæozoic times as it does now. As these old sandstones decay their grains fall apart, and are subject to the action of winds of the same force and direction as those which carried them to their present positions in primeval times; and the sand grains resume their interrupted journey north-eastward after a delay of perhaps hundreds of millions of years.

The imprints made by drops of rain upon beds of soft clay on the sea shore or beside

lakes show that the rain drops of the earliest ages were of about the same size as they are now, and fell with the same force as in modern storms. The physical evidence of rocks made by the accumulation of sediment under the influence of wind and rain shows that the oldest known climatic forces were of the same power as those which act on the surface of the earth to-day.

The earth's climate has no doubt undergone great variations in special localities. Thus the wind-blown deposits at Loch Assynt were laid down under a drier climate than that of the same region at the present time; but the desert conditions in that district then were doubtless balanced by a heavier rainfall elsewhere. Striking evidence of local climatic changes is given by the former distribution of beds laid down by ice. Thus in China and in the hills behind Adelaide in South Australia there are some rocks, which were formed by the action of glaciers in the Cambrian period, the oldest division of the Palæozoic; and these ancient Australian glaciers flowed down to sea level, although they were situated within a few

degrees of the Tropics. Hence these rocks show that in the Cambrian Period, the oldest time known to the geologist containing many remains of animals, the climates of central China and of South Australia were colder than they are to-day.

The evidence is therefore clear that almost at the beginning of the geological record, instead of the whole earth having had a warm climate, some parts of it were colder than they are now. Later on, in the rocks belonging to the Carboniferous System, there is evidence of the existence of ice and glaciers in various countries in the Southern Hemisphere and in parts of India where there are no glaciers to-day. Thus a band of conglomerate belonging to the Carboniferous System can be traced for great distances in South Africa; it is often full of ice-scratched stones, and was laid down by glaciers. Deposits of the same time and approximately of the same age occur in many parts of Australia and in India. Hence in Carboniferous times, parts of the Southern Hemisphere had a colder climate than they

have at present, though Europe and North America appear to have had a warmer climate then than they have now.

The oldest known climates of the world agree with the theory that the earth has been formed by the aggregation of cold meteorites rather than by consolidation from an incandescent gas. There is no doubt that the earth has passed through a stage during which the crust was warmer than at present; but if the earth originated as a swarm of cold bodies which were heated by collisions and shrinkage, then that hot stage would have been passed through comparatively quickly. The earth would never have reached the extremely high temperature that the centre must have had if the earth had been a nebula of incandescent gas. The hot crust would not have been so steadily reheated from below and would soon have cooled.

Hence the fact that at the beginning of the Palæozoic times, places on the earth had a colder climate than they have to-day, agrees better with the planetesimal than with the incandescent nebular theory.

PART II

THE GROWTH OF THE EARTH'S SURFACE

CHAPTER IV

THE FORMATION OF THE EARTH'S CRUST

THE earth probably began as a collection of cold meteorites, but it passed through a stage in which the surface was warmer than it is now. During the crowding of the meteorites into a dense mass they must have come into violent collisions and thus been made very hot. But a more permanent source of heat was the contraction of the mass after the meteorites had all come into contact. It has been mentioned (p. 44) that the heat of the sun is not due to the burning of its materials, but to the process of close packing of its materials, which is constantly proceeding. It has been estimated that the burning of a mass of coal the size of the

sun would not maintain the sun's heat for as much as three thousand years; while the great German physicist Helmholtz showed that the process of contraction would be an adequate source of the sun's heat.

Heat generated by contraction is due to the fact that if a body loses energy, that energy passes away in some other form. Thus a body resting upon the top of a wall possesses, in consequence of its elevation, a power which it will have lost when it has fallen to the ground. The latent energy possessed by the stone in its raised position is given forth as heat on its fall. The contraction of a swarm of meteorites may be regarded as a process of slow falling toward the centre of the swarm; and the fall is necessarily accompanied by the generation of heat. According to Helmholtz the heat of the sun could be maintained by a contraction of sixteen inches a day, or of one mile in its diameter every eleven years.

The heat produced in iron meteorites by their contraction would rapidly spread through them, as their materials are excel-

lent conductors of heat. Hence the meteoritic mass would soon attain a uniform temperature within, and gradually become cooler by the loss of heat from the surface. The heat of the contraction would doubtless be sufficient to melt some of the materials; but they could only melt near the surface, as the pressure in the deeper layers would prevent the expansion that takes place when solids become liquid. Hence the centre of the mass would be kept solid by pressure. The more easily melted materials in the outer layers would become liquid and float to the surface, while the more viscid material might be squeezed out by the contraction of the stronger metallic constituents. The stony materials would thus be slowly forced to the surface and there solidify as a rocky crust.

When an ore is melted in a furnace the earthly constituents are separated from the metallic. The metals collect in the lower part of the furnace and are covered by the stony constituents or slag. Similarly when a swarm of meteorites is welded by heat

and pressure into one mass, the constituents will arrange themselves as a central metallic mass covered by a stony crust.

Although we have not contrived any direct access far into the interior of the earth, the existence of a great metallic core has been shown to be most probable by determinations of the weight of the earth. The materials which form the crust of the earth are on the average about two and a half times as heavy as an equal bulk of water. The earth as a whole weighs more than five and a half times as heavy as a globe of water of the same size. The materials of the inner earth are therefore twice as heavy as the rocks on the surface. The simplest explanation of the great weight of the interior is that it consists largely of metals. The earth therefore consists of two main parts—the stony crust known as the lithosphere, and a heavy metallic mass known as the barysphere, from the Greek word *barus*, meaning heavy.

The existence of this metallic barysphere is further indicated by the evidence of radio-

activity. It has been shown by Professor Strutt that the radio-active energy of the surface of the earth can be supplied by the amount of radio-active materials within a layer forty-five miles deep. If the materials at a greater depth were radio-active, the radio-activity on the surface should be much greater than it is. It therefore appears that below the depth of forty-five miles there are no radio-active materials. The iron meteorites are among the few materials which are not radio-active; and the fact that the barysphere agrees with them in this respect, is a further indication that it is composed largely of nickel-iron.

The crust of the earth therefore consists of rocks which have solidified like a slag from a molten state. Every rock is composed of one or more kinds of minerals. Those minerals that cannot be separated into two or more other minerals by such mechanical processes as washing their powder in water, or sorting the fragments by hand, are known as "simple minerals" or "mineral species."

Many of these mineral species may be formed by melting a mixture of their constituents and letting it solidify. Other common minerals, on the other hand, cannot be thus artificially produced. The mineral species that can be made by simple melting include olivine, the pyroxenes, the garnets, brown mica, the basic felspars (anorthite, labradorite and oligoclase), and the variety of silica known as tridymite. The mineral species which cannot be formed by simple melting include hornblende, the felspars rich in alkalies, quartz, white mica, topaz and tourmaline. Quartz, for example, has a very simple composition; it is composed only of silica, a compound of one part of silicon with two of oxygen. If silica be melted and then crystallised it may form a silica-glass, or such minerals as tridymite, or at a higher temperature the mineral cristobalite; but it never forms quartz.

The mineral species found in rocks may therefore be divided into two groups; those of the first group can be made from molten material; those of the second group, such as

quartz and the acid felspars, require for their formation more complicated conditions, including the presence of intensely heated water, heavy pressure, and often the help of some reagent known as a catalyser, which enables a reaction, that would otherwise take place with extreme slowness, to proceed rapidly.

The first rocks formed on the surface of the earth would naturally be those composed of minerals that could be formed by simple melting. These minerals belong to the series which, owing to their poverty in silica, are known as basic minerals; some of the most important contain ferrum (iron) and magnesium as their chief constituents, and are therefore called femic, a word formed from the letters Fe and Mg, the chemical symbols for those metals. The most familiar rock rich in these basic minerals is basalt; and it is therefore probable that the first rocks formed on the crust of the earth resembled basalt. Later on rocks composed of minerals rich in acid and alkalies would be formed beneath the basaltic layer; and of these deeper-

formed rocks the best known representative is granite.

Hence the first stage in the geological history of the earth is its separation into three divisions—the central metallic barysphere and a rocky crust composed of two layers; the lower layer would be rich in quartz and alkalies and consist of acid rocks; the upper layer would be composed of the heavier minerals, rich in iron, magnesium and lime, and would consist of basic rocks.

CHAPTER V

THE EVIDENCE OF EARTHQUAKES AS TO THE INTERNAL STRUCTURE OF THE EARTH

EARTHQUAKES also supply instructive evidence as to the internal composition of the earth. An earthquake is a wave-like disturbance of the surface of the earth. A stone dropped into a pool of water creates a wave which travels outward from the point where the stone enters; and a sudden movement, dislocation, or explosion in the crust of the earth similarly causes a wave-like motion which travels in all directions from the point of origin and is felt as an earthquake. The rate of advance of the wave varies with the nature of the material through which it passes. A wave made by the fall of a stone into mud is smaller and travels to a shorter distance than if it fell into water. When an earthquake wave passes from a denser to a

less compact material, the wave varies in character as well as in speed.

The velocity at which earthquake waves travel through the earth, therefore, gives information as to the nature of its material. The majority of earthquakes are produced by movements in the earth's crust along faults (see p. 102). A wave-like vibration

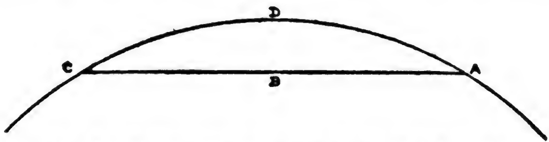


FIG. 5.—Earthquake paths along the arc ADC and chord ABC.

passes outward from the fault affected and is felt to a distance dependent on the violence of the movement on the fault. Some earthquakes are so powerful that they shake the whole earth. An earthquake shock may pass from its point of origin to the antipodes either along the surface of the earth or straight across the middle. An earthquake wave which begins at a point A (Fig. 5) may shake a distant area by passing along the

straight line ABC through the interior; or it may travel around the surface along the line ADC. The point C will feel the shock along ABC sooner than the shock which travels along the outer curve of the earth on the

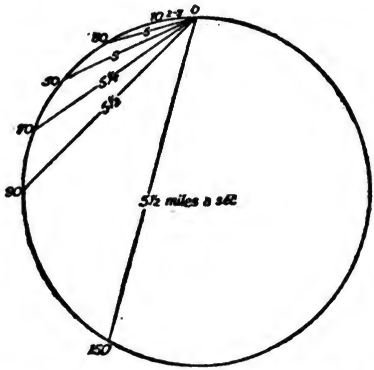


FIG. 6.—The velocity of earthquake waves through the earth. (From the estimates of Professor Milne.)

The figures show the speed in miles per second of earthquakes travelling on the straight lines from 0, where the earthquake started.

path ADC; because the chord AC is shorter than the arc ADC. An observer at C might be shaken twice by the same earthquake; he would feel first the shock that has travelled along the chord and then that which has

travelled around the arc. Professor Milne has shown that if a locality feels an earthquake which has originated so far away that the straight line between the two places goes deep into the earth, then the earthquake is felt sooner than it would be if the shock travelled through the interior at the same rate as through the crust. Professor Milne in fact calculates that the earthquake wave passes through the material in the middle of the earth at the speed of 5.58 miles per second, whereas the same wave would pass through the crust at the rate of only 1.86 miles per second. The velocity of earthquakes in the interior is illustrated by Fig. 6, prepared from Professor Milne's estimates. He therefore concludes that the material in the centre of the earth is very much denser than that upon the crust. He believes that the interior consists of a sphere of a heavy metallic material, allied to that of the iron meteorites. He has called this rock geite, as it forms the chief constituent of the earth. Professor Milne concludes from his calculations of the depth at which the speed of

an earthquake wave is increased by the change in the nature of the material that the rocky crust of the earth has a thickness of about forty miles. Below that depth is a uniform ball of geite.

Mr. R. D. Oldham has carried inferences from the rate of earthquake waves still further. He claims that not only is there a marked difference between the rocky crust and the denser internal material, but that the interior can itself be divided into two distinct zones. He holds that the earth has a central core, about two-fifths of the earth's diameter in size, which is composed of quite different material from that of the surrounding zone.

Mr. Oldham's conclusion as to the triple division of the interior of the earth is based on the fact that an earthquake shock travels through the earth in waves of three kinds. The first includes the large surface waves which travel like the ripples on a sheet of water. The two other kinds pass through the interior of the earth. One of them is a wave of compression due to the particles

moving backward and forward along the earthquake path; the other is a wave of distortion which tends to twist the material traversed by the earthquake.

The waves of compression and distortion pass through the interior of the earth and they arrive at any locality more than seven hundred miles distant from the origin before the large surface waves. They are felt as a series of preliminary tremors before the main earthquake shock, which has travelled around the surface. The waves of compression and distortion do not arrive at exactly the same time. Thus at a place which is a quarter of the circumference of the globe distant from the point of origin of the earthquake the wave of compression arrives according to Mr. Oldham in fifteen minutes by travelling at the rate of 6.2 miles per second, while the wave of distortion arrives there in twenty-five minutes, having travelled at the rate of 3.73 miles per second. The wave of compression, moreover, travels to any distance through the interior of the earth at a fairly uniform rate. This wave from an earth-

quake due to a disturbance on the Equator would travel straight through the earth to the Poles at the rate of 6.21 miles per second. It would cross the centre of the earth and reach its antipodes on the opposite point on the Equator at the rate of six miles per second. The wave of distortion, however, varies more greatly in its speed. It would reach the nearest point on latitude 60° following a straight line through the earth with a velocity of 3.46 miles per second; it would go to the North Pole at the speed of 3.73 miles per second, and to a point on the other side of the earth in latitude 60° at the speed of 3.94 miles per second. If, however, it should go still deeper into the earth, its rate of advance would diminish, so that if it emerged at a locality on the opposite meridian at a point 30° from the Equator, the speed would have fallen to 2.82 miles per second, and it would reach the opposite point of the Equator at a speed of 2.63 miles per second.

There is, then, according to Mr. Oldham, a central core of the earth which is composed

of material so different from the material around it, that it checks the advance of the wave of distortion; and the depth to which a wave has to pass in order to be affected by

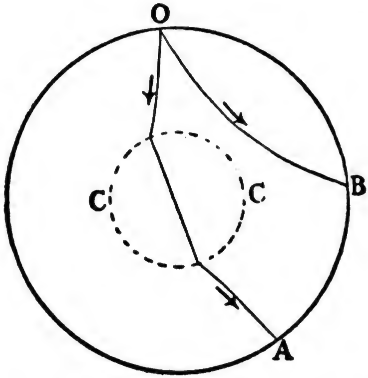


FIG. 7.—The inner core of the earth (after Oldham).
The outer circle represents the circumference of the earth; the dotted circle (CC), the inner core; OA, the course of a wave of distortion which enters the inner core; OB, the course of a similar wave through the thick shell.

this decrease in speed indicates that the diameter of this core is two-fifths that of the earth (Fig. 7, CC). The wave of compression shows somewhat the same result, but its speed is diminished to a smaller degree.

The decrease in speed of a wave of distortion compels it to follow a bent path; hence according to Mr. Oldham a wave of distortion that passes near the centre of the earth follows such a line as that of OA in Fig. 7.

This theory has been both adversely criticised by some authorities and accepted by others. Professor Knott [1] thinks that it is based on an inadequate number of observations; and it differs from the conclusions of Professor Milne, who regards the whole earth below the forty-mile crust as uniform in composition. If, however, Mr. Oldham's views be substantiated by further evidence, then the earth consists of a central core of unknown material, of a thick metallic shell, and a thin skin composed of a rocky crust.

[1] C. G. Knott, *The Physics of Earthquake Phenomena*, 1908, pp. 228–234.

CHAPTER VI

THE BENEFICENT INFLUENCE OF SEGREGATION

THE beginning of the geological history of the earth was therefore the segregation of the materials of the constituent meteorites into three zones. The making of the earth into a condition suitable for the abode of life and ultimately the home of man was by the continuation of this beneficent process of segregation. The tendency of similar materials to collect together in groups has a world-wide influence. Its results have affected the world from the primeval knotting of the nebula to the crowding of people into towns and the restriction of various industries to special districts. These human segregations are often deplored, but they continue in spite of all efforts to stop them. They go on in obedience to an impulse which affects inorganic matter as well as living beings.

Segregation converted the widely diffused nebulæ into planetary knots, and then divided each young planet into a metallic centre and a stony crust. Further segregation was essential to the development of life, the existence of man, and the establishment of civilisation. But for segregation the metals which man requires for tools would lie at depths beyond his reach. The phosphorus required to fertilise soil would be scattered in such tiny particles through the igneous rocks that they could not be used for the enrichment of poor land. Quartz, which owing to its hardness and durability is useful as building stone and polishing sand, was useless while scattered as one of the constituents of deeply buried rocks. Clay, the fine-grained material which now prevents the rain water from sinking to useless depths, is of service when collected into beds sufficiently pure to serve its important function of collecting water and forming springs. Nitrogen, which is an essential constituent of animal tissues, at first existed as a free gas in the atmosphere

and not in a condition available as food for animals. All the materials required for the life and work of man existed in the rocks of the lithosphere and in the waters of the oceans or in the air; but they were practically useless, until each had been collected into beds from which they could be obtained in the necessary quantity and purity.

This segregation of the materials originally scattered through the crust is a result of three groups of processes. The first group is a series of destructive agencies which break up the rocks of the lithosphere. By the second group the fragments thus formed are sorted out by various transporting agencies, and by the action of a third group the sorted fragments are deposited in beds. What, then, are the processes by which the rocks are destroyed?

The original rocks of the earth's crust were doubtless formed by direct solidification of molten material; all such rocks are called primary rocks. When exposed on the surface of the earth they are broken up and their constituents redeposited; rocks thus

formed are known as secondary. Where primary rocks are exposed on land they are attacked by the constituents of the atmosphere. The air includes oxygen, carbon dioxide (a gas composed of one part of carbon and two parts of oxygen), and water vapour. These materials all act upon rocks. The oxygen combines with some of the constituents, which expand in consequence of this process of oxidation; others are thus loosened, and the rock decays and falls to pieces.

The carbon dioxide is dissolved from the air by rain; and as the rain water soaks into the rocks the carbon dioxide in it attacks some of the constituents and converts them into carbonates. The silicates are converted into carbonates, and this process is known as weathering. It always takes place, though often very slowly, where rocks are exposed to the action of the weather, and it generally occasions the weakening and decay of the rock.

The water in the air also has a very powerful effect in destroying rocks. The water soaks into them and collects in the pores

and crevices; and if this water freeze at night its expansion tears and cracks the rock and leaves it still more open to the entrance of air and water. Moreover, the carbon dioxide in the water dissolves any carbonates that may be present, and their removal in solution aids the crumbling of the rock. As the surface becomes decomposed the fragments are washed down the hillside by rain, or may be blown away by the wind, and thus fresh layers of rock are exposed to the attack of the atmosphere. The primary rock materials released are used for the formation of other rocks, which, as their materials are derived from the primary rocks, are known as secondary rocks.

The secondary rocks cover a large proportion of the earth's surface, and they are especially important as they form the foundation of the areas which are most densely peopled, wealthiest, and most important politically. Thus in Scotland the primary rocks occur mainly in the Highlands, while the Lowlands, which include the chief cities and industrial centres, consist mainly of

secondary rocks. In England primary rocks form some of the moors of Cornwall, Dartmoor and Shap Fell; but secondary rocks occupy nearly the whole of the kingdom, and include all the chief manufacturing, agricultural and mining districts.

The secondary rocks may be distinguished from primary rocks by four chief characters.

1. The primary rocks are composed of crystalline materials or a mixture of crystals and natural glass; and these constituents solidified at the time of the formation of the rock. The secondary rocks, on the other hand, are composed of broken fragments of primary rocks; they are therefore known as "clastic," from the Greek word "Klastos," meaning broken. The separate grains of a sandstone are crystalline in structure like the quartz in a granite; but whereas the quartz in the granite crystallised as an original constituent of the rock, the quartz grains in a sandstone are broken fragments of crystals which were formed elsewhere.

2. The primary rocks were formed under conditions of high temperature and solidified

from a molten state. They are accordingly known as igneous rocks. The most abundant of the secondary rocks, on the other hand, were formed by the action of water, and they are therefore often all grouped together as aqueous rocks. Those beds, however, which were laid down as wind-blown deposits on land are known as æolian deposits.

3. As the secondary rocks have been laid down by the action of water or wind they generally occur spread out in wide horizontal sheets or layers. They are therefore called stratified rocks, from the Latin word "stratum," a layer. The primary rocks having no such regular arrangement in layers are therefore "unstratified." They reached the positions where they were first formed in a molten state, and solidified sometimes deep below the surface in great blocks known as "massifs," at other times as sheets known as dykes or sills which were forced into the rocks of the crust; at other places again they were poured out as lava flows over the surface.

4. As the primary rocks are generally

formed from masses of molten material they do not contain any remains of life, for neither animals nor plants could exist where those rocks were formed. The secondary rocks, on the contrary, contain the remains of the animals and plants which were living at the time when these rocks were being deposited. Such remains entombed in the rocks are known as fossils. The secondary rocks are therefore often fossiliferous. Study of the fossils found in the secondary rocks shows whether they were formed on land or in water, and if the latter, whether in the sea, or in a lake, or on the bed of a river.

The structures of the primary rocks show the condition under which they were formed and whether the materials solidified upon the surface of the earth under volcanic conditions, or at great depths below the surface as "plutonic rocks," or as dykes and sheets at comparatively slight depths below the surface.

Some secondary rocks contain no fossils; but the conditions under which they were produced may be learnt from the shape and

arrangement of their particles. The layers may have been laid down regularly under deep sheets of water or in very irregular confused layers under the influence of strong currents along the shore; or they may have been piled up on land, and if so both the forms of the grains and the arrangement of the layers may show whether they were deposited as sand dunes or as widespread sheets of wind-borne dust.

The great importance of the secondary rocks as the foundations of the areas of the greatest economic value renders it usually more important to distinguish the different kinds of these rocks than it is to identify the various igneous rocks.

The secondary rocks belong to four chief groups—the sandstones, clays, limestones and coals.

The members of the sandstone group are composed of grains of sand. The grains are originally laid down in beds of loose sand. When the grains become slightly cemented to one another the material passes into the condition of sand-rock. The further cement-

ing of the grains produces sandstones; and if the separate particles are so firmly united that the stone breaks as readily across the grains as through the cement between them the rock is a quartzite.

In the British Isles the common sandstones are composed of fragments of quartz, but in some countries the chief beds of sand and sandstone are composed of other materials. Thus the coral sands of the Pacific Islands consist of carbonate of lime, and some sandstones consist of similar grains which have been cemented into firm rock. Other sandstones, moreover, are formed of grains of felspar.

The essential property of a sandstone is, therefore, not its chemical composition, but the size of its particles. The smallest size of a sand grain is .005 mm., or one five-thousandth of an inch in diameter. A material composed of smaller particles is known as clay or silt. The sandstones are of main service to man as building stones.

Conglomerates are rocks allied to the sandstones, from which they differ by the larger

size of the constituents, which are pebbles instead of being grains. When the pebbles are loose they form beds of gravel and shingle. If the pebbles have been cemented together they form the rock known as conglomerate if the pebbles are rounded, and as breccia if they are rough and angular.

The clays form the members of the argillaceous series, and they differ from sandstones owing to the much finer size of their particles. A sedimentary clay is deposited in the form of mud. One common variety of clay divides into thin regular horizontal layers, and it is known as shale. Slate is a member of the clay series, which has been subject to such great pressure that its particles have been rearranged and it breaks into very thin regular slabs.

The clays are of great value as owing to their softness they readily decay on the surface and give rise to beds of rich soil. They are, moreover, easily levelled by the weather into smooth plains, and they form the foundation of much of the most valuable agricultural land. The clays are also very

useful owing to their impermeability to water; they therefore prevent the rain water which falls upon them sinking to useless depths underground. The water is held up by the sheets of clay, and either collects in water-bearing strata from which the supplies may be obtained by wells, or it discharges on the surface in springs which maintain the flow of rivers through the dry seasons of the year.

The third important group of secondary rocks, the calcareous series, includes the limestones, which are rocks composed of carbonate of lime. This material is dissolved in water (as bicarbonate), and it is extracted by various animals and plants, which use it to build up their shells and skeletons. On the death of these organisms their hard parts collect in a litter upon the sea floor and these accumulate as calcareous beds which may be cemented into limestone. In some cases the carbonate of lime is precipitated from the water by chemical processes and then forms beds of calcareous tufa or chemically deposited limestones.

The limestones are of great service to man, as building stones, for the manufacture of cement, because of their capacity of holding large stores of underground water, and because they give rise to fertile soils which are especially suitable for the growth of cereals.

The last series of rocks are the carbonaceous, which include those of which the chief constituent is the element carbon. Their main value is as the chief supply of fuel and oils. The formation of the carbonaceous rocks can be seen at the present day in peat bogs, where decomposed vegetable material collects in thick beds on cold wet moorlands. If a deposit of peat be covered by clay or sand, and then buried for a prolonged period under a thick heavy layer of rocks, it would be slowly altered into the fossil fuel known as coal.

The coals have been formed from accumulations of vegetation of different kinds which have grown under different conditions. The most important supplies of coal in the world occur in the rocks of the Carboniferous System; and these coal seams were formed

on the sites of old forests or collected as masses of decomposing vegetation on the floors of swamps or lagoons.

The coals are of five chief kinds—

1. Brown coals or lignites, which are mostly of comparatively recent formation, are of a brown color, and usually fairly soft.

2. Household coal, which is used for ordinary domestic purposes; it is hard, black and brittle, and is mostly mined from the Carboniferous System.

3. Cannel coal or gas-coal, which readily gives forth gas that burns with a bright white flame. This coal was of high value for gas manufacture before the introduction of incandescent mantles.

4. Oil shale, a variety of coal which contains a large proportion of earthy material; when slowly heated oil is distilled from it.

5. Anthracite, the varieties of coal which are richest in carbon and give off the greatest heat per ton of fuel. They burn without flame or smoke, and are therefore most suitable for naval purposes.

A country which is composed of two such rocks as basalt and granite will give rise to a very varied series of secondary rocks. Basalt consists of a basic felspar and the two minerals, olivine and pyroxene. Granite consists of an acid felspar, quartz and mica. The composition of these minerals and the products formed by their destruction is shown in the following table—

Rock.	Mineral Species.	Constituents.	Redeposited in Secondary Rocks as
Basalt	Basic Felspar	Silica, Alumina	Clay
		Lime	Limestone (carbonate of lime)
		Soda	Salt (Sodium Chloride)
	Pyroxene	Silica	
		Iron	Ironstone
		Magnesia	In clays and limestones
	Olivine	Silica, Magnesia	In clays and limestones
	Magnetite	Oxide of Iron	Ironstone
Granite	Quartz	Silica	Coarse grains as sand and sandstone; finest particles as clay
	Acid Felspar	Silica, Alumina	Clay
		Potash	Potash salts
		Soda	Common salt
	White Mica	Silica, Alumina, Potash	Fine Flakes of Mica

Hence the destruction of the primary rocks and the redeposition of their constit-

uents leads to the formation of the chief kinds of secondary rocks—namely sandstones, clays and limestones.

What are the processes by which the primary rock material is shifted? There is the wind that blows away the lighter particles; these may be carried far afield and deposited as clay and loam, while the larger fragments are left as boulders and pebbles, which may be gradually reduced in size by the wearing of sand that is blown against them. The quartz grains that fall from the decomposing granite are blown along by the wind, and rolled over the ground, until they are dropped in some sheltered spot, or, stopped by moisture or some solid obstacle, become piled up as a sand dune.

There are streams and rivers that will carry primary rock material for greater or less distances depending upon the speed of the current and the weight of the mineral particles. Boulders are torn from mountain sides and sent crashing along by ever-flowing torrents. Pebbles are rolled slowly along the bed of the stream, and are soon worn

into powder. Sand grains are swept along the river bed, and collect as sheets of sand as soon as the current loses strength. The finest particles are carried much farther and deposited as beds of clay where the current is slow. So a bather often finds in the same river, where the current is quick, there is a gravelly or sandy bottom; where the current is slow, the bottom is of clay.

There is the sea constantly wearing away the land by the attack of its waves upon the coast. The waves undermine the cliffs and the upper parts fall on to the beach. The fallen blocks are broken by the surf into shingle, and all the material obtained from the wearing back of the shore is moved along the coast by the tide. The beach material is thereby sorted into banks of shingle on exposed positions, beds of sand where the coast is somewhat more protected, and sheets of clay in quiet bays and at a little distance from the shore-line. These deposits are gradually converted into rocks. The clays are hardened by pressure into shales. The sand is cemented into sandrock and sand-

stone, and beds of gravel or shingle into conglomerate.

What now is the third group of processes by which beds are deposited from primary material? Besides the simple mechanical processes of wind- and water-transport of rock material, there is a more subtle form of transport. The materials dissolved from rocks are carried along in solution until they are extracted from the water by animals, plants and chemical processes. Many animals and plants have shells and skeletons of carbonate of lime, which is obtained from the different salts of lime in solution in fresh or sea water. On the death of the organism the hard parts collect on the floor of the lake or sea, and thus give rise to beds of limestone. Some siliceous rocks are formed of the hard parts of sponges, and the microscopic creatures known as radiolaria and diatoms. Phosphate beds are formed of phosphate of lime derived from the bones of animals, or by the action of phosphoric acid in sea water upon grains of carbonate of lime.

Another process of segregation is due to

the action of plants. Most plants extract carbon dioxide from the atmosphere and use the carbon in the formation of their tissues. If large quantities of vegetable material are buried together, they may be converted into such material as peat and ultimately into coal.

Chemical processes lead to the formation of other useful materials. Some limestones are formed by carbonate of lime being deposited from the water of springs and streams. On the evaporation of arms of the sea or lagoons the sea salt is laid down in beds of common salt.

Hence by various mechanical, organic, and chemical processes the materials originally scattered through the rocks of the earth's crust and floating in air or water are collected into layers and form beds of sand, clay, limestone, salt and the various mineral fuels, including peat and coal.

In process of time the primary rocks exposed on the earth's surface are all broken up and their materials used to form second-

ary rocks. Nevertheless there are still large areas of country formed of primary rocks, for fresh masses are continually raised to the surface from below as fast as the upper layers are destroyed and removed. The earth is still slowly shrinking, and as the crust sinks downward irregularly it presses with unequal force on the underlying material. Some of the fluid or plastic rocks below may be driven beneath some weak area and uplift it, and then solidify under the pressure of the overlying crust.

Rocks formed deep below the earth's surface are known as plutonic, after Pluto the God of the Infernal Regions; they generally occur in large masses which have been forced among the overlying materials. These plutonic rocks often give off tongues or sheets, which force their way through the overlying rocks; such sheets are known as dykes and sills. If these dykes reach the surface, their molten rocks are discharged in volcanic eruptions. Where the rocks discharge upon the surface in molten streams they form sheets of lava. If the rocks are

saturated with steam, it escapes in explosions which blow the stony material into small fragments; and they fall around the volcanic opening and build up a round hill. The hollow in the centre of this hill is a volcanic crater. The lava sheets from many separate vents may join to form continuous lava fields covering many thousands of square miles.

The rocks which rise from the interior of the earth are charged with water and gases, which escape from volcanoes in great clouds. As the plutonic rocks cool beneath the surface, their waters slowly work their way upward; as the waters are very hot they dissolve any particles of metals with which they come in contact, and bring them to the surface in solution. While the hot waters cool they deposit the metals dissolved in them as mineral veins. In this way metallic constituents scattered as minute grains through the primary rocks are collected into veins, from which they can be profitably mined.

CHAPTER VII

THE UPLIFT OF THE LAND

ALL the natural processes by which land is being lowered are grouped together under the name of denudation. The result of denudation would be in time the lowering of all land to sea level. The processes of denudation although usually slow are unceasing, and in many localities they are deplorably rapid. Some British coast lands have even been worn away during historic times.

The land, however, is maintained by movements in the crust which counteract denudation. In many areas there is an automatic readjustment, by which the land is raised by uplift from below as fast as it is lowered by denudation. Scandinavia has been standing above sea level since very early geological times. It has been subjected to the attack of the denuding agents for so long a

period that it would all have been planed down into lowland or even reduced to a bank covered by the sea, if it had not been raised as fast, and at times even faster than it has been lowered by denudation. The rugged form of the country and the raised beaches along the Norwegian coasts both show that in recent times the uplift has been greater than the denudation.

The coal fields of south-western Scotland supply a good illustration of the struggle between the denuding and the uplifting forces. The coal seams occur in successive layers through a series of deposits over 4000 feet thick. The character of these rocks shows that they were all deposited either a little above or a little below sea level. Many of the deposits were formed on land; but beds of limestone and shales which were deposited in a shallow sea occur occasionally throughout the whole series. These carboniferous rocks were laid down sometimes in estuaries, sometimes as beach deposits, sometimes in the shallow water along the shore, and sometimes as forests on low-

lying coast land. These 4000 feet of deposits were not formed in an already existing depression; for any such basin would have been occupied by sea water, and the first beds deposited on its floor would have the characters of deep-sea deposits. As the depression was slowly filled the beds would indicate deposition under shallower conditions until they reached sea level; and above the continuous series of marine beds would follow the beds laid down on land. But the whole of this vast thickness of sedimentary rocks in the coal fields of south-western Scotland were deposited close to sea level; the beds of limestone were formed when a slight subsidence had submerged the land along the coast. The deposition of fresh beds of sediment again filled up the shallow sea; the newly formed land would be covered by forest or swamp and fresh accumulations of vegetable matter laid the foundation of another coal seam. This layer would be covered by sand and silt, and on a further subsidence the sea would again cover the district, and be again driven out by the deposition of sands and clays.

In spite of this constantly changing geographical condition the average rate of the deposition of sediment was the same as the average rate of the sinking of the ground. If the sinking had been too rapid thick sheets of limestone and marine beds would have been formed. But the rate of deposition has kept pace with the rate of sinking for such prolonged periods and in so many parts of the world, that the agreement can hardly be a mere coincidence. Sir Archibald Geikie, in his lecture on Geographical Evolution to the Royal Geographical Society in 1879, stated that "among the thickest masses of sedimentary rock—those of the ancient palæozoic systems—no features recur more continually than the alternations of different sediments," which, with the accompanying surfaces covered by ripple-marks, worm-tracks, and cracks due to drying, "unequivocally point to shallow and even littoral waters. They occur from bottom to top of formations, which reach a thickness of several thousand feet. They can be interpreted only in one way, viz. that the formations in ques-

tion began to be laid down in shallow water; that during their formation the area of deposit gradually subsided for thousands of feet; yet that the rate of accumulation of sediment kept pace on the whole with this depression; and hence, that the original shallow-water character of the deposits remained, even after the original sea-bottom had been buried under a vast mass of sedimentary matter." [1]

The rates of subsidence and deposition of sediment are so often the same that the probabilities appear overwhelming that there must be some direct connection between the two. The most probable explanation is that the extra weight of the fresh sediment itself causes the sinking of the area over which it is spread; and the lightening of the adjacent land by the removal of a layer of sediment enables it to rise. The newly raised land is then attacked by denudation, a fresh layer of material is transferred from the land to the sea floor, which therefore sinks again; and the process is continued indefinitely.

[1] *Proc. R. Geog. Soc.*, New Series, vol. i, 1879, p. 426.

In addition to movements due to adjacent areas being in this "isostatic balance" there are uplifts and subsidences due to changes within the crust. The inflow of plutonic material beneath an area will cause an uplift, while the contraction of the central mass of the earth causes the sagging downward of the weaker parts of the crust.

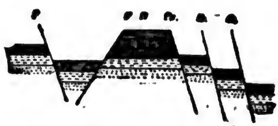


FIG. 8.—Normal Faults.
FF, Trough Faults.
H, Horst.
Fs, Step Faults.

The problem of isostasy—the theory that each block of the earth's crust is upheld by the weight of adjacent blocks—is admittedly one of great difficulty. The truth of this principle was doubted by many geographers in spite of the strength of the geological evidence in its favour; but the investigations by Professor E. O. Hecker on the value of the force of gravity at sea shows that the

evidence of physical earth measurements is consistent with the isostatic theory.

The uplifted and sunken areas may be separated by movements along fractures known as faults. A fault is a displacement by which rocks are broken across and sink or rise to different levels (Fig. 8, F). In normal faults (as in Fig. 8) the rocks sink downward on what is known as the down-

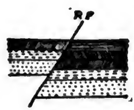


FIG. 9.—Reversed Faults.

throw side. The beds are left at a higher level on the other side, which is called the upthrow side. The reverse occurs in a reversed fault (Fig. 9). A band of rocks may be lowered between two parallel faults which together form a trough fault (Fig. 8). A block of land may be left upraised between two parallel faults forming a "horst" (Fig. 8, H). A bed may be lowered by successive faults into a succession of steps by step faults (Fig. 8, Fs).

In addition to displacements due to vertical movements there are others due to pressure from the sides. Pushing a cloth across a table throws it into a series of folds; and the earth's crust is often bent into folds by pressure from the sides. The ridges or upfolds are known as anticlines (Fig. 10, A). The troughs or downfolds are known as

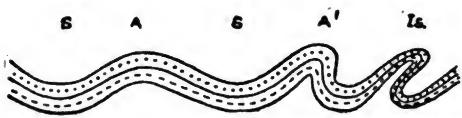


Fig. 10.—Diagram of Earth Folds.
S, Syncline.
A, Anticline.
A', Asymmetrical Anticline.
Is, Isocline.

synclines (Fig. 10, S). The folds may be broad and gentle as in Figure 10, A, or they may be narrow and one side of a fold may be thrust under the other side, so that both limbs of the fold are inclined in the same direction. Such compressed folds are known as isoclines (Fig. 10, Is).

The disturbances of the earth's crust produce mountains which may be classified into

four chief groups—Block-mountains, Fold-mountains, Residual-mountains and Volcanic-mountains. Each kind is due to a different geographical process.

Block-mountains consist of blocks of the earth's crust which stand above the level of the neighbouring country. Their elevation is generally due to the subsidence of adjacent blocks. Block-mountains are sometimes formed by the tilting of blocks of the crust, the edge that forms the crust of the mountain having been upraised along a fault or the lower edge having been depressed by subsidence. Block-mountains may perhaps be also formed by the uniform uplift of parts of the earth's crust, though the possibility of such movements is denied by some geologists.

Fold-mountains are formed by the crumpling of the earth's crust. The folding may be due either to side pressure buckling the surface into alternate ridges and valleys like a sheet of corrugated iron. They may also be caused by a vertical uplift due to the intrusion of great masses of igneous rock, and this type of disturbance produces great dome-

shaped swellings rather than series of parallel ridges. The simplest variety of fold-mountains includes those composed of gentle regular folds, such as are represented on the left-hand side of Fig. 10. If the lateral pressure be more intense the folds are crowded together and the two sides are not similar (as in Fig. 10, A′), or the two sides may slope in the same direction as in isoclines (Fig. 10, Is). If the pressure be still more severe the fold may be broken and the upper part pushed forward along slightly inclined or nearly horizontal faults. Such faults are known as thrust-planes. In consequence of these movements old rocks are pushed above younger rocks, and the ordinary succession of beds in a district is inverted. The combination of over-thrusting and folding is characteristic of such complex fold-mountains as those of the Alps.

Residual-mountains are so called because they are remnants of large sheets of rock, the rest of which has been removed by denudation. A block-mountain or plateau is attacked by the different agencies which wear

away the surface of the earth. The rocks are splintered by heat and shattered by frost. The gases in the air cause chemical decay of the rock constituents; and sand which is blown by the wind against cliffs and exposed rock surfaces cuts them away. Rain washes the loose debris down the hillsides, and masses left unsupported slide down steep slopes as land-slips. The materials thus lowered into the floors of the valleys are carried away by streams, and the valleys are themselves steadily enlarged by the action of rivers and wind and sometimes by ice. Hence a raised block of the earth's crust is slowly eaten away. Its surface becomes jagged and irregular. Valleys are cut deeply into the mass, and the ridges and summits left between them form residual-mountains.

Volcanic-mountains are vast heaps of lava and volcanic tuffs, piled up around volcanic vents. A simple volcano usually forms a conical mountain with a central pit or crater above the mouth. When volcanoes are denuded the soft loose materials are swept away; a hard core of rock solidifies in the

pipe through which the volcanic materials have arisen. This core is left as a hill which is known as a volcanic neck. Some volcanoes pour forth vast floods of lava which bury the surrounding country beneath thick sheets of rock; the flows from many separate volcanic vents may unite into one continuous sheet, and thus a wide range of country may be buried beneath a deluge of lava. The level parts form lava plains and the thicker masses or parts that have been left upraised by subsequent earth movements stand up as lava plateaus.

PART III

THE PLAN OF THE EARTH

CHAPTER VIII

THE INCONSTANCY OF OCEANS AND CONTINENTS

THE greatest of the areas of subsidence on the earth's crust are the deep ocean basins; the regions uplifted or left elevated between the oceans form the continents. In the history of the making of the earth it is a question of primary importance whether the elevated and sunken areas have always occupied the same positions as at present.

The frequent interchange between land and sea is one of the best-established of geological facts. Nearly every part of England, for example, has been many times alternately raised above and submerged beneath the sea. A limitation in the extent of these changes was suggested by the work of the famous *Challenger* Expedition, whose in-

vestigations between 1872 and 1874 laid the basis of our present knowledge of the oceans. One of the most startling discoveries made by that expedition was that the deposits which are spread over the floor of the oceans are quite different in character from those formed near the coasts, and they are unlike any that were then known among the materials of the land. The floors of the oceans far from land are covered with deposits known as ooze. Some kinds of ooze are composed largely of the remains of microscopic animals and plants, mixed with a very fine clay which represents the undissolved residue of volcanic dust that has fallen into the sea, or of very fine dust that has been blown off the land. They may also contain fragments of broken up meteorites, and the teeth of sharks which are now extinct. Some oozes consist mainly of red clay derived from volcanic ash.

At the date of the *Challenger* Expedition no rocks were known which agreed in character with these deep-sea deposits, and accordingly the theory was advanced that no continent

had ever been buried beneath a deep ocean. The marine deposits found on the lands were attributed to formation in shallow seas and in areas near land. Similarly it was held that though the margins of the oceans may be raised above sea level the central ocean basins had lasted throughout the whole of geological time. Lord Kelvin made the interesting suggestion that the oceans and continents had even been outlined in the nebula by the formation of areas of especial stability which have always remained as continents.

Further support in favour of the permanence of the continents was claimed from the evidence that the earth's crust beneath the oceans is of heavier material than that which forms the continents. It is held that owing to this difference of weight the ocean floors have always kept at the lower level.

The evidence for the permanence of the continents and oceans was summarised by Dr. A. Russel Wallace in one of the most interesting chapters of his *Island Life* (1880, pp. 81–102). His concluding summary (*op. cit.*, pp. 101, 102) laid stress on the sedimentary

deposits having all been formed near the coasts, on their being so variable in character that they rarely retain the same character for 150 or 200 miles, on the formation of the bulk of all strata near land, on the absence of deep-sea oozes among known rocks, and on the repeated occurrence of shore, estuarine and lake deposits among all sedimentary rocks. Dr. Wallace claimed that lacustrine beds were formed in every period of the earth's history from the Cambrian onward and in every continent, and that they "complete the proof that our continents have been in existence under ever-changing forms throughout the whole of that enormous lapse of time."

The oceans, according to Dr. Wallace, are shown to be permanent by their great depth, their wide extent, and the extraordinary fact that the islands in the great oceans "never contain any Palæozoic or Secondary rocks." New Zealand and the Seychelles are, he says, the only exceptions, "leaving almost the whole of the vast areas of the Atlantic, Pacific, Indian, and Southern Oceans without

a solitary relic of the great islands or continents supposed to have sunk beneath their waves."

The theory of the permanence of the oceans is, however, less widely held than formerly, owing to the new evidence as to the geology of the oceanic islands and the distribution of animals and plants. Deep-sea oozes, moreover, have been found raised above sea level, and their absence from the continents is easily explained. The presence in these deposits of the teeth of extinct sharks and the comparative abundance of meteoritic debris shows that the deep-sea oozes form extremely slowly. They are probably always thin, and most of their constituents are so light that if an area of ooze be raised near sea level, wave action during storms would churn it up, and the drift of the ocean water and currents would sweep it away. It would probably be only under very exceptional circumstances, as when the oozes have been uplifted rapidly in areas of quiet sea, that such deposits could survive the passage through the surface waters. True deep-sea oozes have now been

found above sea level, as in Barbados, Cuba, Borneo, and some South Pacific Islands. These raised fossil oozes are all of comparatively recent geological age. The careful description by Mr. Jukes-Browne and Professor Harrison of the deep-sea deposits of Barbados has proved that the oldest deposits in that island were laid down in an estuary. The area was then submerged beneath the sea to abysmal depths, at which various types of deep-sea oozes were formed; and then these deposits were raised above sea level. They were protected during their elevation through the surface by a cap of coral limestone; and some of them still remain, 1200 feet above sea level, on the highest hills of Barbados.

The only reply to this evidence given by the advocates of the permanence of the ocean basins is that Barbados is on the edge of a great volcanic area, and rapid oscillations of level in such a district does not prove that a continental area may be submerged beneath an oceanic abyss.

Some areas in the world have remained as

land throughout nearly the whole of known geological time, and perhaps through all of it. Thus Scandinavia and Finland have apparently never been completely submerged. The sea has frequently washed the shores of that area, and its margins have been occasionally covered by the sea; but the area as a whole appears to have been land, since the beginning of the geological record. Labrador, the peninsula of India, large parts of Africa, and most of western Australia have also stood above sea level throughout geological time. As these lands have been permanent it is probable that some parts of the deep oceanic basins may have been covered by water throughout the earth's history. Nevertheless, there is strong evidence that the arrangement of land on the globe has been very different at different geological periods.

The most important evidence on this subject is given by the distribution of animals and plants. The world at the present time is divided into seven zoological regions—

1. The Neoartic Region, including North America as far south as Mexico.

2. The Neotropical Region, consisting of South and Central America.

3. The Palearctic Region, including Europe, Asia (except the south-eastern corner), and India, and the region of the Atlas Mountains in northern Africa.

4. The Ethiopian Region, comprising all Africa except the part included in the Palearctic Region.

5. The Oriental Region, consisting of the peninsula of India, south-eastern Asia and parts of the Malay Archipelago.

6. The Australian Region, including Australia, Tasmania, New Guinea and some adjacent islands.

7. The New Zealand Region, which, owing to its exceptional fauna, is a small independent region.

These seven zoological regions were founded mainly on the evidence of the birds; and their limited distribution is the more striking as no other land animals have such powers of migration from one region to another. The existence of these regions show that even birds are confined by geographical

boundaries to certain restricted areas. The birds of Africa are different from those of South America because they are separated by the Atlantic, which has prevented their passage from the one region to the other.

The distribution of the mammals requires a different arrangement of zoological regions. Thus Lydekker from the evidence of mammals divides the world into three geographical realms; they are Arctogæa, which includes North America, Europe, Asia and Africa; Neogæa, which consists of South America and Central America, and Notogæa, which includes Australasia and Polynesia. He subdivides Arctogæa into five regions, the range of which is shown on Figure 11. According to the evidence of other groups of animals the zoological resemblances between Africa and South America are so striking that these continents have been regarded as one zoological region.

The fundamental difference between the geographical distribution of various groups of animals is most easily explained as due to the different arrangement of ocean and continent at the times when these groups were

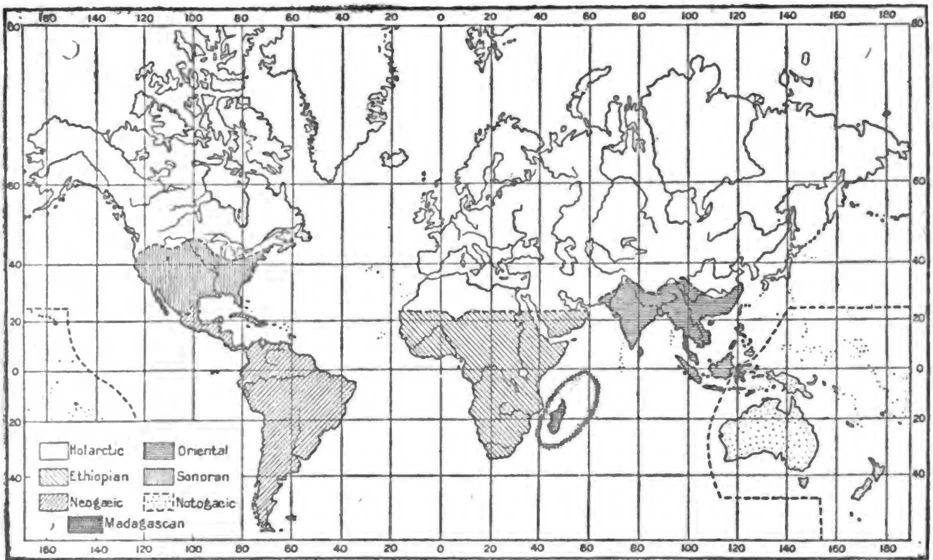


FIG. 11.—Lydekker's Classification of the Zoological Divisions, according to the Mammals.

evolved. Animals which appeared at one time in the earth's history found different land lines available for their migrations.

Thus the marsupials with two front teeth in the lower jaw (Diprotodonts), of which

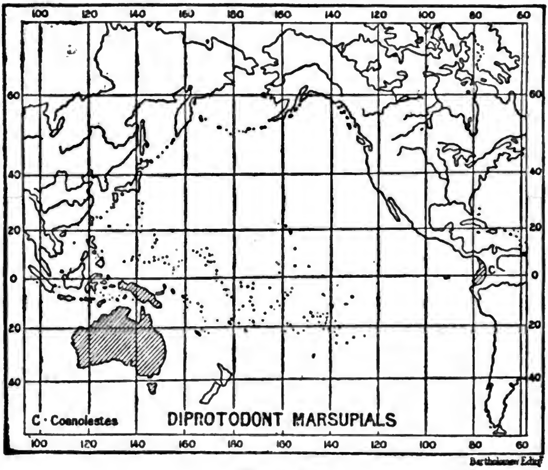


FIG. 12.

the kangaroos are the best-known representatives, now live only in Australia and a few adjacent islands, with the exception of one animal, Cœnolestes, which lives in South America in the northern Andes. The fossil remains of some extinct animals regarded by

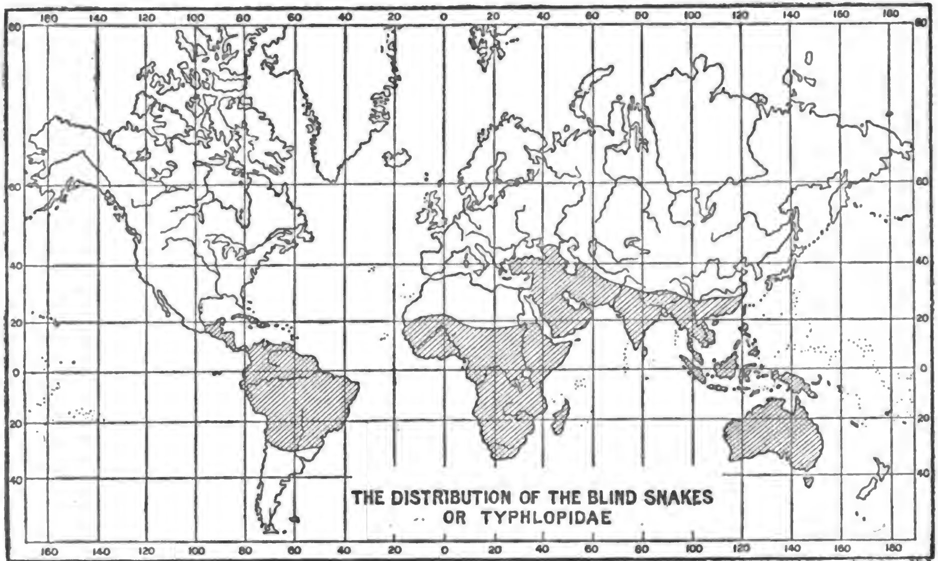


FIG. 13.

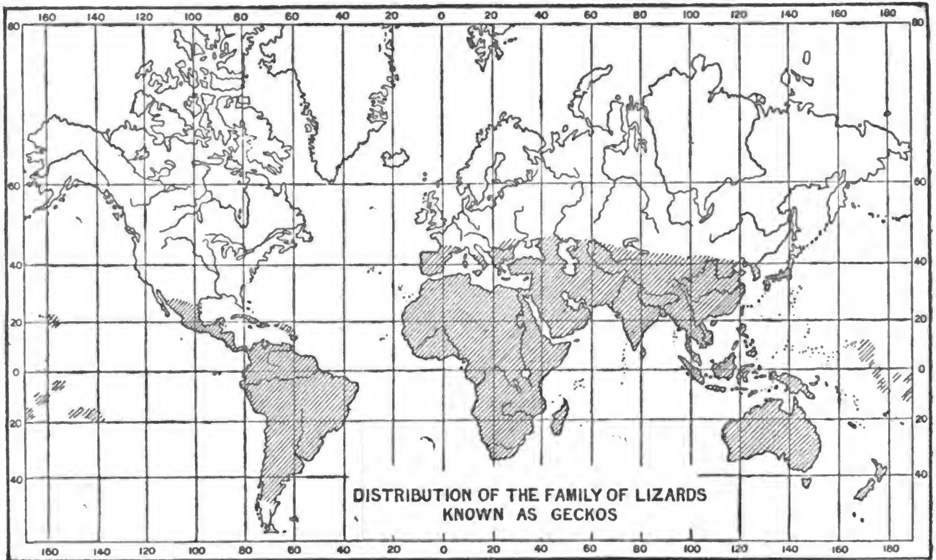

DISTRIBUTION OF THE FAMILY OF LIZARDS
KNOWN AS GECKOS
Bartholomew, Edin.

FIG. 14.

many authorities as Diprotodonts, have been found in Patagonia. The presence of marsupials with more than two front teeth in the lower jaw (Polyprotodonts) throughout South America and in the northern parts of North America, as well as in Australia, can be explained by their being the survival from a time when they were nearly world-wide in distribution. Their fossil bones have been found in Europe and Asia, where they have been exterminated by higher types of mammals. They have lived on in Australia protected from competition, as that region was separated from Asia before the arrival of the more highly developed mammals. Marsupials with the two large front-teeth in the lower jaw are known only from Australia and South America; there is no evidence that they passed from the one region to the other across the lands of the Northern Hemisphere, and they indicate that there was formerly some southern land connection between Australia and South America (Fig. 12).

This conclusion is supported by the distribution of various groups of animals which

now live in Australia, Africa and South America, but they are quite unknown in the northern lands of the world. They therefore probably spread through the Southern Hemisphere by lands which have now disappeared between the oceans. Thus Fig. 13 shows the distribution of the blind snakes known as the Typhlopidæ, which are found in Central and South America, in tropical and southern Africa, in India and Australia. They do not occur in Europe, North America, nor in the main part of Asia. The tree-snakes of the family Dipsadomorphidæ have very much the same distribution, and so also have the lizards known as the Geckos, which are also found in New Zealand (Fig. 14). The frogs of the family Cystignathidæ are found (Fig. 15) in Australia, Tasmania, South America and in the New World, where they range as far north as Mexico and southern Florida; hence if they had crossed from Australasia to America across Europe or Asia it is strange that their only known locality in the United States is in southern Florida. A somewhat similar geographical

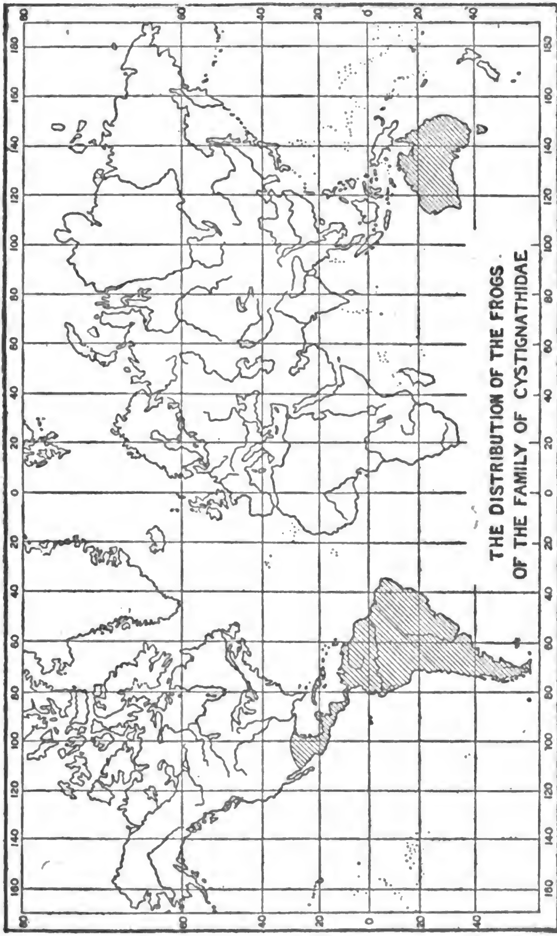

THE DISTRIBUTION OF THE FROGS
OF THE FAMILY OF CYSTIGNATHIDAE

FIG. 15.

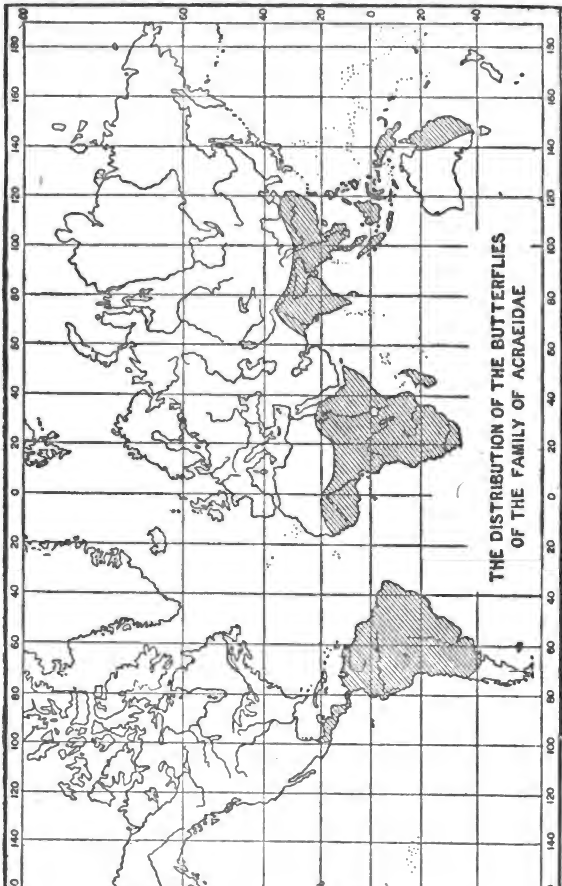

THE DISTRIBUTION OF THE BUTTERFLIES
OF THE FAMILY OF ACRAEIDAE

Fig. 16.

range in animals with quite different habits is found, for example, in the family of butterflies known as the Acræidæ, which live (Fig. 16) in South America, the Oriental Region of Asia, and Australia, with the addition of South Africa.

Hence, as these groups of animals have a wide range across the Southern Hemisphere and are unknown in northern lands, their distribution can be most reasonably explained by a direct land communication in the Southern Hemisphere connecting South America, Africa, India and Australasia. These animals are aborigines of the Southern Hemisphere and have never inhabited the main northern lands, though they have crossed the Equator into India, northern Africa, and Central America.

The evidence of the southern groups is supported by that of animals which are restricted to the Northern Hemisphere and have never spread to the south. Thus the true stag-beetles (*Lucanus*) inhabit (Fig. 17) North America, Europe, the Atlas region of Africa and Asia; but they are absent from

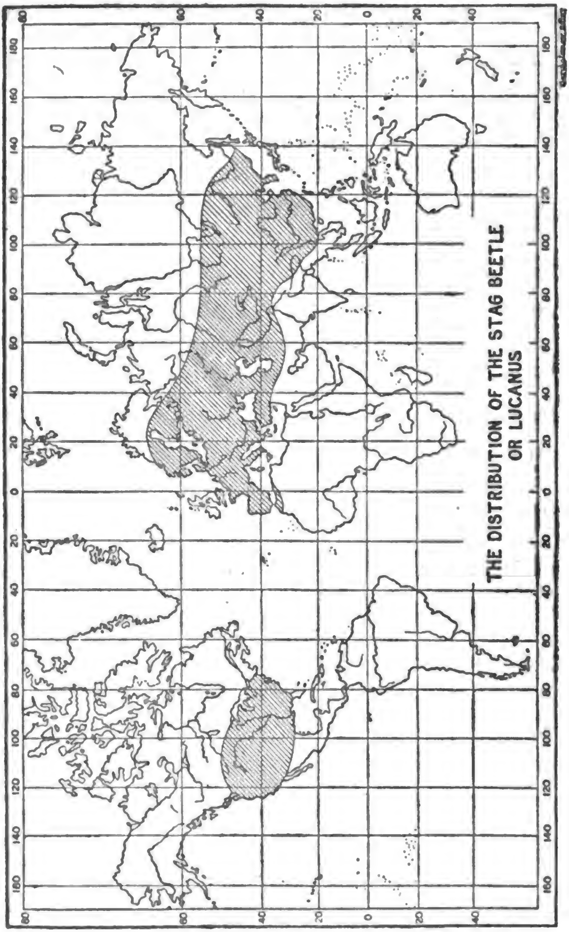


FIG. 17.

South America, Africa south of the Atlas, southern India, and Australia.

The evidence of extinct animals and plants is even more striking. The same kinds of gigantic land tortoises lived in Australasia and Patagonia, and if they had crossed from the one country to the other by a northern route, some traces of them should have been found in the northern lands. Their distribution requires a land connection in the Southern Hemisphere. The distribution of the extinct plants confirms that of animals. The range of the known plants of Carboniferous times shows that a continent must have extended then from the middle of South America eastward to Australia, and included the Highlands of Brazil, Africa, India, and probably the whole of the Indian Ocean. This ancient continent is known as Gondwanaland from the area in India where its deposits were first studied (*cf.* p. 184).

The evidence, therefore, of the distribution of animals and plants proves the former existence of continents that have been dismembered and of land routes that have foundered beneath the oceans.

CHAPTER IX

THE PLAN OF THE EARTH

THE value of the earth to man depends on the intimate mingling of the land and the sea. The climates of the politically important regions and the water supply to which the lands owe their fertility depend on the constant passage of air to and fro between land and sea. The area on the earth covered by water is more than two and a half times as much as that occupied by land. The relative proportions are estimated as about two-sevenths land and five-sevenths water. According to a more detailed measurement, seventy-two per cent. of the earth's surface consists of water and twenty-eight per cent. of land.

If all the land of the globe were collected into one continent around one Pole the conditions of life on the earth would be so entirely different that it is doubtful whether

the human race could have come into existence. The fundamental problem of geography is the cause of the distribution of land and water on the globe. Dr. Newbigin, in the volume on Modern Geography in this series (p. 19), adopts the sound definition of geography as the subject which "deals with the surface-relief of the earth, and with the influence which that relief exercises upon the distribution of other phenomena, and especially upon the life of man."

The value of the earth to man depends upon the arrangement of the surface relief, since that determines the distribution of land and water. The lands of the world are the parts where the surface is raised, while the oceans occupy the intervening hollows.

The distribution of land and sea appears at first sight irregular and haphazard. But from the earliest times geographers have been impressed with certain geographical features, which indicated that the arrangement of land and water were based on a definite plan. The classical geographers recognised that the chief tracts of land and water

around the eastern Mediterranean extended outward in radial lines, and they knew that to the west, the south-east, and probably also to the north the lands were bounded by a vast surrounding ocean. Hence they represented the lands of the globe as a wheel-shaped island surrounded by sea. This idea was expressed still more simply in the "wheel maps" of the medieval geographers, in which the chief geographical units were represented like spokes, all radiating from Jerusalem.

The discovery of America shattered the primitive "wheel maps," but it led to the recognition of further striking geographical agreements between disconnected lands. Thus Bacon pointed out the resemblances in the course of the two sides of the Atlantic in the following passage—

"But although they [physical parallels or resemblances] be not of much assistance in discovering forms, yet they are of great advantage in disclosing the frame of parts of the universe, upon whose members they practise a species of anatomy, and thence occasionally lead us gently on to sublime and

noble axioms, especially such as relate to the construction of the world, rather than to simple natures and forms.

"Lastly we must particularly recommend and suggest, that man's present industry in the investigation and compilation of natural history be entirely changed, and directed to the reverse of the present system. For it has hitherto been active and curious in noting the variety of things, and explaining the accurate differences of animals, vegetables and minerals, most of which are the mere sport of nature, rather than of any real utility as concerns the sciences. Pursuits of this nature are certainly agreeable, and sometimes of practical advantage, but contribute little or nothing to the thorough investigation of nature. Our labour must, therefore, be directed towards inquiring into and observing resemblances and analogies, both in the whole, and its parts, for they unite nature and lay the foundation of the sciences.

"Here, however, a severe and rigorous caution must be observed, that we only consider as similar and proportionate instances,

those which (as we first observed) point out physical resemblances; that is, real and substantial resemblances, deeply founded in nature, and not casual and superficial, much less superstitious or curious, such as those which are constantly put forward by the writers on natural magic (the most idle of men, and who are scarcely fit to be named in connexion with such serious matters as we now treat of), who, with much vanity and folly, describe, and sometimes, too, invent, unmeaning resemblances and sympathies.

"But leaving such to themselves, similar instances are not to be neglected, in the greater portions of the world's conformation, such as Africa and the Peruvian continent, which reaches to the Straits of Magellan; both of which possess a similar isthmus and similar capes, a circumstance not to be attributed to mere accident.

"Again, the New and Old World are both of them broad and expanded towards the north, and narrow and pointed towards the south." [1]

[1] Bacon: *Novum Organum*, Book II, Aph. 27, pp. 194–199 of Pickering's edition, 1844.

Fuller knowledge of the geography of the world has increased the number of features which indicate that all the lands of the globe have been shaped and distributed in accordance with some ancient, deep-based plan. These features are known as geographical homologies; and according to our present knowledge, they may be divided into four.

The first homology is the predominance of land in the Northern Hemisphere and of sea in the Southern Hemisphere. The Northern Hemisphere contains a great excess of land over sea, and the Southern Hemisphere an undue proportion of sea. Maps illustrating this unequal distribution of land and water are given in most geographical text books.

The second geographical homology is the triangular shape of the geographical units. Lands and seas are very often triangular. The triangles are somewhat irregular, but one of the most conspicuous features of a map of the world is the preponderance of irregularly triangular forms. Further the triangles of land have their bases to the north and taper southward, as is the case in North

America, South America, Africa and India. Consequently the oceanic triangles are widest to the south and taper northward, as is the case with the Pacific Ocean, the different basins of the Mediterranean, the Arabian Sea and the Bay of Bengal; and the North Atlantic would be brought into agreement with this rule by the elevation of the submerged ridge which runs from Greenland past Iceland to Scotland. The well-known geographical dictum that all peninsulas point southward is an expression of this rule; and though there are several exceptions to the usual direction of the peninsulas it is significant that with the two best-known exceptions, Yucatan ends off abruptly in a long straight edge to the north, and Denmark tapers southward to the narrow isthmus of Schleswig.

The third of the geographical homologies is the natural result of the first two. The lands of the world form a nearly complete ring around the Northern Hemisphere, and project southward from this ring in three pairs of continents. The northern land belt

is broken by Bering Strait and the North Atlantic. The latter, which is the only wide break in the continuity of the northern lands, is of comparatively modern date, for Greenland was connected by land with Scotland in recent geological times. From the northern land belt the continents project southward along three meridional lines, America, Eur-Africa (to use Professor Lapworth's term for Europe and Africa), and Asia with Austral-Asia.

The oceans in their turn form a complete circle around the Southern Hemisphere and project northward, gradually tapering between the widening lands.

The fourth homology is the most significant, but it is the least generally understood. It can be better recognised by observation of a globe than of a map. It is the antipodal position of land and water. The ends of any straight line passing through the centre of the earth and reaching the surface are the antipodes of one another; and any such line which has land at the one end is almost sure to have water at the other. If a globe be

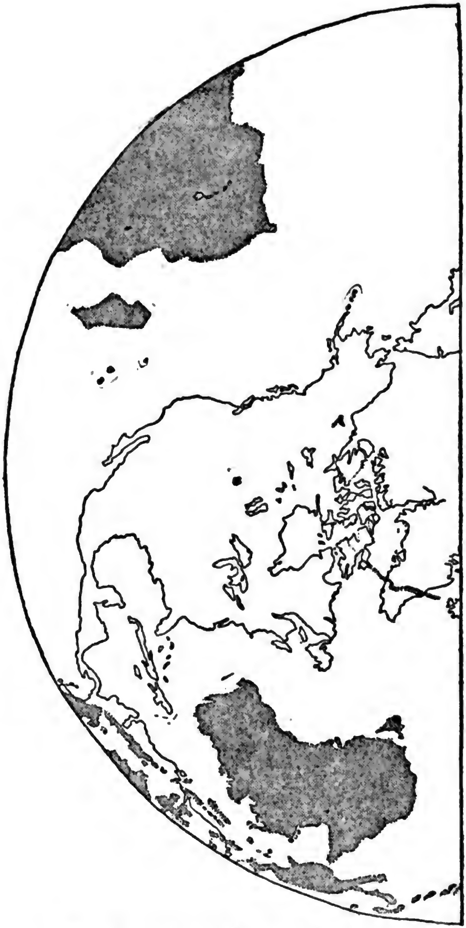


FIG. 18.—Antipodal map of the world.—The
Hemisphere projected on to their

shaded areas represent the lands of the Southern antipodes in the Northern Hemisphere.

rolled about upon a table, when land occurs at the top of the globe, then the part touching the table nearly always shows sea. Each of the continents is "antipodal" to an ocean. The antipodal position of land and water is illustrated by the accompanying map (Fig. 18), which shows that Australia is antipodal to the North Atlantic, Africa and Europe to the central area of the Pacific, the Antarctic Continent to the Arctic Ocean, North America to the Indian Ocean and the adjacent area of the Southern Ocean, the northern part of South America to the China Sea and the western Pacific. The only considerable land area which does not follow the rule is the southern part of South America, which is antipodal to parts of China. The rule, however, is so general that only one twenty-seventh of the land of the world has land antipodal to it.

The four previous homologies in the distribution of land and water determine the present plan of the earth. Its most striking feature on inspection of a map is the lack of

symmetry in the arrangement of land and water between the Northern and Southern Hemispheres; and this asymmetry suggested the ingenious explanation of the facts which we owe to Lothian Green.

It was early recognised that the forms of the continents were determined by the arrangement of their mountains; these act as a framework upon which the land has been built up. Hence the mountain chains were called "the backbones of the continents." The formation of the mountains was attributed to the crumpling of the earth along great cracks in its crust. The first serious attempt to explain the distribution of land and water by connecting it with the mountain system of the world was by the distinguished French geologist Elie de Beaumont. He regarded the earth as a sphere with the crust traversed by a regular network of intersecting cracks; and he represented these cracks as cutting up the surface of the world into twelve five-sided areas or pentagons. He classified the mountains of the world according to their directions in reference to

the lines of this pentagonal network. The great defect in his scheme is that his network is precisely the same for the Northern and Southern Hemispheres, whereas the fundamental difference between these two hemispheres is the most conspicuous feature in the plan of the earth.

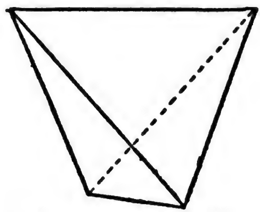


FIG. 19.—A tetrahedron.

Lothian Green recognised that the plan of the arrangement of the lands on the earth agrees rather with the tetrahedron than with the figure enclosed in twelve pentagons. The tetrahedron is the body bounded by four equilateral triangles (Fig. 19). It has four triangular faces which meet on six edges and project in four corners or "coigns." The nature of the tetrahedron and the tetrahedral distribution of land can be best understood by making a simple model.

Copy Figure 20 on a piece of white cardboard, and cut away all outside the outer edge of the figure. Then with a sharp penknife cut half through each of the straight continuous lines marked on the diagram. The card can then be folded along these lines, until the edges meet; fasten the sides together by gum or preferably seccotine on

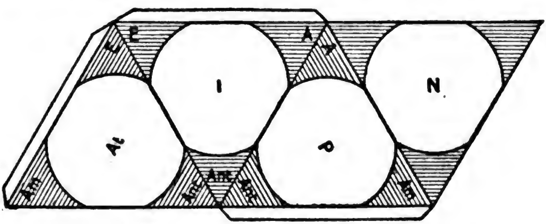


FIG. 20.—Net of a tetrahedron.

the inturned flaps. The model will then form the kind of triangular pyramid known as the tetrahedron.

It will be seen by turning this model about on a table that each of the four projecting coigns is opposite one of the four faces.
coign is always antipodal to a flat face.

Paint in blue the four circles; their area together equals five-sevenths of the area of

the tetrahedron, which is the proportion of the earth's surface occupied by water.

Drive a knitting-needle through the centre of the face marked N, and push it out at the

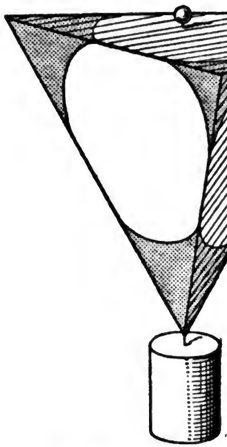


FIG. 21.—Mounted tetrahedron.

opposite coign. Then mount it on a cork so that the needle is vertical and the face N is the top of the model (Fig. 21). Now if a volume of water could be held upon the surface of a tetrahedron by attraction from the centre of the body, as water is held on

the surface of the earth, the water would collect first in the middle of the four faces because they are the parts nearest the centre of the mass of the model. If the volume of water was just large enough to cover five-sevenths of the surface of the tetrahedron, then the water would cover the middle of each face and meet the areas of water on the adjoining faces on the middle part of each edge. Land and water on this tetrahedron would be distributed as follows:—There would be a circular ocean on the top face and, letting the N marked on that face stand for the North Pole, the sea around it would be the Arctic Ocean. This ocean would be surrounded by a nearly complete ring of land consisting of the three projecting coigns; and each of these lands would project southward and end in three triangular projections into the southern seas. The last continent would represent Antarctica around the South Pole and would be antipodal to the Arctic Ocean. Each of the three side faces would include an ocean tapering northward and united on each southerly side to the adjacent oceans.

These oceans would represent the positions of the Indian, Pacific, and Atlantic Oceans. The complete ring of water around the Antarctic continent would correspond to the Southern Ocean and the southern Pacific.

The model will then show the striking general resemblance of the distribution of land upon the earth to the raised parts of a tetrahedron and of the oceans to the flat faces. The model will have a northern Arctic Ocean antipodal to the Antarctic continent. The coign marked Am. will represent America; and it is antipodal to the ocean marked I, the Indian Ocean. The coign E represents the position of Eurafrica, and it is antipodal to the ocean P, the Pacific. The third projection AA will represent Asia-Australia and will be antipodal to the ocean At., the Atlantic.

The lands moreover form a nearly complete circle around the Arctic Ocean and they taper southward in triangular peninsulas corresponding to the three meridional pairs of continents on the earth.

The southern part of the model has a

complete oceanic girdle surrounding the Antarctic continent.

Hence *if a volume of water could be held by gravity on a tetrahedron, so as to cover five-sevenths of the surface, the arrangement would be approximately that of land and water on the earth.*

As the elevations on the earth, which form the continents, correspond in arrangement with the elevated portions of a tetrahedron, then the plan of the land on the earth may be called tetrahedral. The chief differences are that whereas each of the three sides of the tetrahedron are exactly alike, the shapes of the oceans and continents differ in detail; and Europe and Asia are united instead of being separated like America and Asia.

The North Atlantic, however, at no distant geological date was separated or almost separated from the Arctic Ocean by land which extended from Scotland through the Faroe Islands and Iceland to Greenland. This land was at one time doubtless continuous and was broken up into a chain of islands which have been diminished by the

enlargement of the channels between them. But if we restore this former land, which is still marked by a belt of comparatively shallow sea, then the North Atlantic would

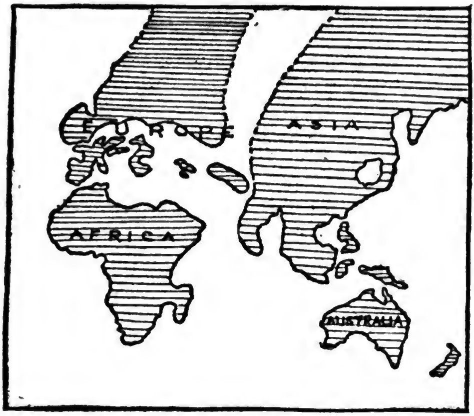


FIG. 22.—The former separation of Europe and Asia. (From a Map of the World in Oligocene Times by Prof. H. F. Osborn.)

taper northward to a point and so come under the general rule.

Similarly the present connection of Europe and Asia is due mainly to a wide tract of low country which, in comparatively recent geological times, was submerged by the sea

(Fig. 22). The Persian Gulf and the Caspian Sea are upon the site of a sea which formerly separated Europe and Asia, if they are not actually relics of such a sea. The presence of seals in the Caspian Sea is a well-known indication of its former connection

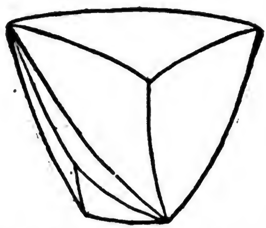


FIG. 23.—A tetrahedron with convex faces.

across Russia with the northern seas. If the Russian lowlands were submerged, Europe and Asia would be united only by the narrow belt of comparatively young fold-mountains between the Caspian and the Persian Gulf. The tetrahedral plan of the earth in these two respects has therefore been obscured by recent earth movements.

The earth, however, is not a tetrahedron, for that shape could not be maintained in

any body with a structure like that of the earth and rotating with its high rate of speed. If the earth were a fixed body it might, and probably would have acquired a tetrahedral shape; but owing to its rapid rotation it necessarily becomes rounded.

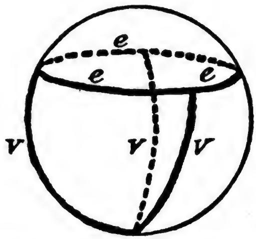


FIG. 24.—Traces of the edges of a tetrahedron on a sphere.

If a tetrahedron be constructed with its edges made of strips of thin whalebone and its faces of elastic tissue, and air be pumped into the model, the sides bulge out and become convex (Fig. 23). Further increase in the internal air pressure would cause the edges to bend outward, and by further bulging out of the sides the tetrahedron would gradually become a sphere. Three of the six tetrahedral edges (Fig. 24, *e*) would form

a circle on the upper side, and the other three (*v*) would occur as vertical edges running down from the circle and meeting at

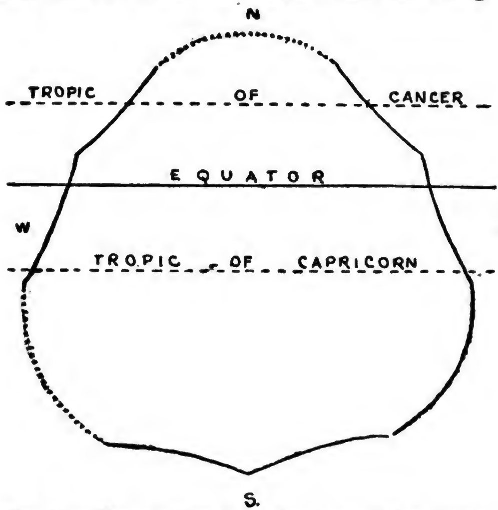


FIG. 25.—The primitive form of an ocean (after Lothian Green).

the lowest coign (Fig. 24, *v*). If the air be allowed to escape from such a sphere, the first change in shape would be a flattening around four points into four faces, and it would thus gradually pass back again into the condition of a tetrahedron.

The curvature of the surfaces of the tetrahedron would also render the shapes of the ocean and continents less regular and more

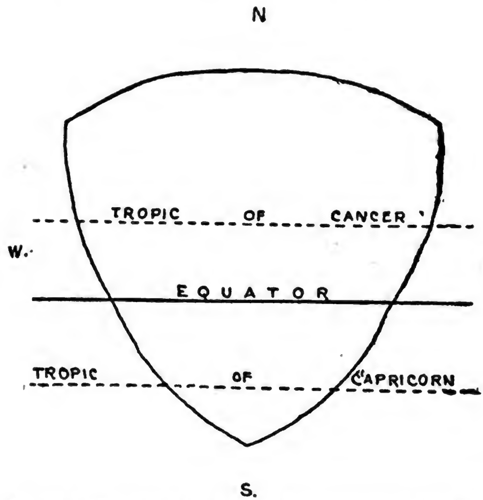


FIG. 26.—The primitive form of a continent (after Lothian Green).

similar to those that exist on the earth. Instead of the oceans being circular they would be bounded by a series of curved lines, and Lothian Green has shown that the primitive form of an ocean on such a tetrahedron

would be that of Figure 25, which has striking resemblance to that of the Pacific. Similarly the primitive form of a continent would be bounded by six convex lines, as in Figure 26, which recalls the features of Africa and South America.

Lothian Green's theory regards the world not as similar to a plane tetrahedron with four triangular sides, but as a six-faced tetrahedron with curved faces. This body is formed by placing a six-faced pyramid on each face of the tetrahedron; and if the twenty-four faces of this body are suitably curved it will approximate closely to a sphere.

The earth is a body which is continually shrinking owing to the contraction of its internal mass;[1] and its rigid shell does not shrink to the same degree. Every globular

[1] The great weight of the earth's interior (see p. 61) has also been explained as perhaps due to the compression of the material by the pressure of the overlying rocks. If so, it would not be safe to assume that the internal mass is contracting more than the crust. The recent evidence, however, strongly supports the view that the heaviness of the interior is due to its metallic composition; it is, therefore, most probable that the internal mass shrinks more than the crust—a conclusion which is consistent with the geological evidence.

body under such conditions tends during contraction to become tetrahedral. This tendency is readily explained, for the sphere is the body which has the smallest surface in proportion to its volume. The tetrahedron on the other hand is the regular body which has the largest possible surface for any given volume. Any hard-shelled body which is contracting by internal shrinkage is encumbered with an excess of surface; and a globular body can most readily dispose of this extra surface by approximating to the form of a tetrahedron. The excess of surface is disposed of with the least movement by flattening on four faces. Hence balloons composed of a skin of uniform thickness pass during their collapse through a tetrahedral form; and the same shape is observed in air bubbles and hollow balls under external pressure.

The tetrahedral collapse of a sphere is analogous to the usual method in which short cylindrical metal tubes collapse under external pressure. Green quoted a series of experiments by Fairbairn on the crushing inward of short tubes; and in Fairbairn's

tests short tubes always gave way on three sides, so that the circular tube becomes triquetral, *i. e.* bounded by three concave sides. The original form and the triquetral shape after the collapse of one of the tubes used in Fairbairn's experiments is given in Figure 27. The bending of the tube into this shape may be explained by the antipodal position of the elevations and depressions. If the tube were

FIG. 27.—The transverse section of a short collapsed tube (after Fairbairn). The dotted line represents the original outline—the shaded area the form after collapse.

filled with some comparatively rigid material then it would be expected that the tube should be kept pressed out on the side opposite the part that is forced in. Similarly in a sphere, the collapse at one point would naturally tend to press out the antipodal point. As a short cylindrical tube yields on three faces, a sphere naturally tends to yield on four. The probability of this tetrahedral collapse has been recognised by some authorities on geodesy. Thus, according to

Mr. E. D. Preston, "Nothing is more in accordance with the action of physical laws than that the earth is contracting in approximately a tetrahedral form. Given a collapsing homogeneous spherical envelope, it will assume that regular shape which most readily disposes of the excess of its surface dimensions, or, in other words, the shape that most easily relieves the tangential strains; for, while the sphere is of all geometrical bodies the one with a minimum surface for a given capacity, the tetrahedron gives a maximum surface for the same conditions. Experiments on iron tubes, on gas-bubbles rising in water, and on rubber balloons, all tend to bear out the assumption that a homogeneous sphere tends to contract into a tetrahedron."

All that we know concerning the rocks in the deeper layers of the earth show that they are more plastic than is the crust; and that the earth is shrinking in volume appears to be the only reasonable explanation of the widespread contortion of the rocks of the earth's crust. Hence it appears inevitable

that the earth must suffer this tetrahedral flattening. If the earth were fixed it might in time become a tetrahedron, but as the tetrahedral deformation is resisted by stresses due to the earth's rotation the earth remains a globe slightly flattened on four faces. The ocean waters collect on these four depressions and form the oceans.

As the tetrahedral deformation flattens one polar area and leaves the other as a projecting coign, the Northern and Southern Hemispheres are dissimilar.

That the figure of the earth is not a sphere or even an exact spheroid [1] is now admitted by practically all the authorities on the shape of the earth. When they speak of the form of the earth, the irregularities on the surface of the solid crust are disregarded. The phrase, "the figure of the earth," as used in astronomy and geodesy, refers to an assumed figure known as "the spheroid of reference." The surface of this spheroid is often defined as the level at which water would stand if it

[1] In a sphere all sections are circular; in a spheroid the equatorial section or any section parallel to it is circular; and all sections through both Poles are oval.

penetrated into the land along an innumerable series of canals. The spheroid of reference is the height of the water level, if the land were all swept away and the earth were covered by a continuous ocean, excluding any variations due to the influence of tide or wind. This assumed figure was formerly regarded as a "spheroid of revolution." If a curved band were stretched over the spheroid of reference from Pole to Pole and were so mounted that it could be moved around the earth on a pivot at each Pole, then if this band remained in contact with the surface of the spheroid of reference throughout its revolution that spheroid would be a spheroid of revolution. It is now recognised that owing to the irregular form of the earth this revolving band would be separated from the surface in some parts of its journey, and the gap left between the spheroid of reference and this revolving band would show the extent of the departure of the earth from a true spheroid. According to Professor Helmert the difference between the form of the earth and a true spheroid is always small.

The difference is one which it is very difficult to determine by measurement; and as the difference is admitted it may be greater than is thought and may have been much greater in former periods of the earth's history.

The shape of the spheroid of reference is, therefore, not a true spheroid, and is best described as a geoid, *i. e.* an earth-shaped body. As Herschell expressed it, the earth is earth-shaped. Instead of its shape being like that of an orange, it is better compared, as Sir George Darwin suggests, to a potato. If the South Polar area projects more than the North Polar, as there is reason to believe, then the shape of the earth may be likened to a peg-top. A horizontal section through a peg-top should be quite circular; but the section through the earth along the equator is not exactly circular, and therefore the earth may be regarded as having the shape of a warped peg-top.[1]

The flattening of the four faces will continue until the conditions become unstable.

[1] Professor Jeans has described the earth as pear-shaped, which is a similar form; but as a pear has a curved axis, the comparison with a peg-top seems the more suitable.

Then the stresses due to the earth's rotation will cause the edges to buckle and collapse, and the world will recover its spheroidal form, though of a somewhat smaller size; and then on this sphere the process of tetrahedral flattening would start again.

As to the rate of shrinkage of the earth we have no certain evidence. It is calculated that the sun must be growing smaller at the rate of a mile in diameter every eleven years. This rate is calculated from the amount of heat given off by the sun; and as the heat that comes to the earth's surface from the interior is very small, the reduction in size of the earth is probably now very slow. One measure is afforded by the horizontal marine rocks of Jurassic and Cretaceous age which occur in wide horizontal sheets on the summits of the high plateaus of western America. They occur up to the height of eleven thousand feet above sea level. As Professor Suess has clearly pointed out, these beds give no indication of having been uplifted. The fractures in them imply that the surrounding areas have sunk. Beds can be up-

raised by folding to the height of twenty thousand feet and more above sea level, as in the Himalaya; but, without denying that beds can be uplifted without being crumpled or disturbed, it is easier to explain the elevated position of such horizontal marine beds as those in the Rocky Mountains by the sea having been at their level during their deposition. The lands which bounded that west American sea must have stood still higher, and if the average height of the land to the west of the country were then 2000 feet above sea level and has sunk below the Pacific to the depth of 15,000 feet, the movement represents a shortening of the radius of the earth by nearly five and a half miles, and of the diameter by nearly eleven miles. A better measure is, however, the difference between the levels of the sea surface at the two dates. These marine beds were not laid down in a deep sea. If we assume that it was 3000 feet deep, the sea level has fallen about three miles since the Cretaceous Period, and the diameter of the earth would be about six miles shorter.

The view that the earth has shrunk so much is opposed to the conclusions of some high authorities. Sir George Darwin has come to the conclusion that the earth has not shrunk perceptibly during geological time; and his opinion cannot be lightly dismissed, though on this point it is a corollary to a somewhat speculative mathematical arrangement. A geologist may therefore be excused for thinking that the widespread contortion of the rocks, which proves that they have been often crowded into a smaller space by side pressure, is unmistakable evidence of contraction of the crust, and therefore of the shrinkage of the earth.

CHAPTER X

THE DEFORMATION OF THE EARTH AND ITS GEOLOGICAL HISTORY

The geological evidence of the past history of the earth is the ultimate test of the theory that the plan of the earth is due to the deformation of a hard crust on four faces, owing to internal shrinkage. There are however such great gaps in our knowledge of the distribution of land and water on the earth, especially concerning the Pacific area, that the test of geological history cannot yet be fully applied. Nevertheless, the general outlines of the earth's history are consistent both with the planetesimal theory and with the arrangement of land and water by tetrahedral deformation of the earth's crust.

The history of the earth is divided into four primary divisions or eras, known respectively as the Archæozoic, the Palæozoic, the Mesozoic and the Kainozoic (see p. 51).

In the oldest of these eras, the Archæozoic, very little is known about the geography of the earth owing to the very great alteration in the condition of the rocks then deposited. One striking feature of all the older rocks of the Archæozoic Era is that they are intensely crumpled in all parts of the earth. When an apple dries its peel is thrown into small wrinkles which cover the whole surface, because the skin is very thin and is therefore easily crumpled. When an orange dries it undergoes changes of shape due to the flattening of parts of the surface, as its skin is much thicker than that of the apple. Similarly, when the earth was so young that its crust was thin, the shrinkage of the earth led to the crumpling of the whole crust. In later times, when the earth's skin was much thicker, the crumplings were restricted to special areas; and the further contraction of the interior was followed by wide areas of the crust collapsing into shallow flat depressions. The crust was deformed, instead of being universally wrinkled.

In the three later eras, the history of the

earth is fully consistent with the occurrence of alternate periods of tetrahedral flattening and spheroidal recovery, for these changes explain many of the leading facts in geological history. For example, although there may never have been a period during the earth's history when volcanic action has been completely dormant, yet it has at certain periods been much more active than at others. Outbursts of world-wide volcanic activity have alternated with intervals of volcanic rest.

The earlier Archæozoic periods were marked by widespread and tremendous volcanic disturbances. They were less frequent and less universal during the succeeding Cambrian period.

The next period, the Ordovician, was one of renewed world-wide volcanic activity, and it was followed by the Silurian, which was characterised by quiet deposition of sediments with few volcanic outbursts.

The Devonian was another great volcanic period, and the earlier part of the Carboniferous, represented in England and Ireland

by the thick series of Carboniferous limestones, was in many countries another interval of quiescence, though great volcanic eruptions were in progress in southern Scotland.

The later part of the Carboniferous and the Permian were marked by the renewal of violent volcanic activity accompanied by important earth movements and mountain building in many parts of the world.

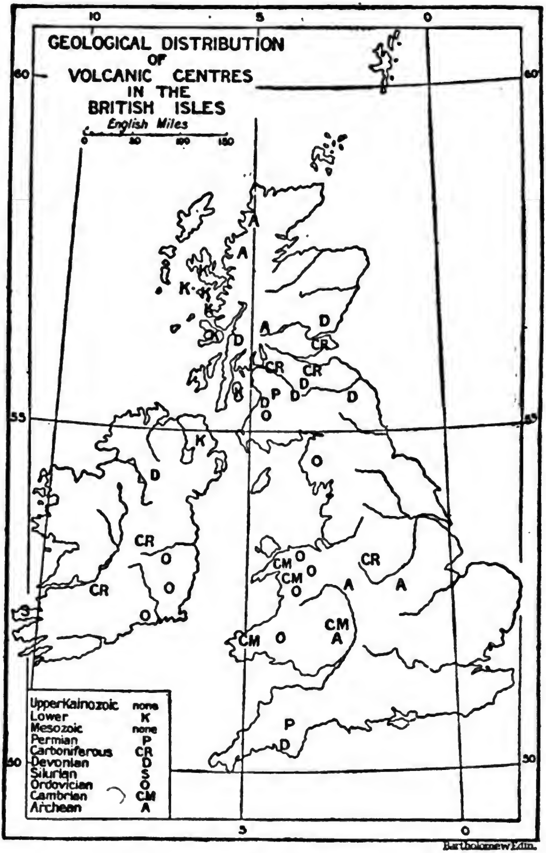
These great outbursts were followed by a long period of quiet, during which the Mesozoic rocks were being deposited. Then in the Upper Cretaceous and Eocene times, when the chalk and the London clay were being laid down in the south-east of England, volcanic activity on a great scale began again; in the Eocene, the earliest period of the Kainozoic, there were volcanic eruptions in Africa and India, in Australia and America; and nearer home the volcanic hills among the western Isles of Scotland may have been built up at this time.

These colossal eruptions were followed by another interval of comparative quiet; this was broken by the widespread volcanic erup-

tions and the world-wide earth movements during the Miocene Period, which formed the Alpine and the Circumpacific Mountain Systems.

This alternation of volcanic activity and quiescence which has lasted throughout geological history is well illustrated in the British Isles (Fig. 28). Our oldest Archæozoic rocks are mainly igneous, and there is evidence that they were accompanied by volcanic outbreaks. In a later part of the Archæozoic era volcanoes were active in various English localities, including the Charnwood Forest, the Malvern Hills, and the Wrekin.

During the last section of the Archæozoic Era in Scotland—the Torridonian—volcanic action was dormant. In Cambrian times volcanic action was of secondary importance in the British area. The Malvern volcano was still in eruption and lava streams were poured out near the northern foot of Snowdon. Near the end of this period the eruptions began in central Wales, which later culminated in the building up of Cader Idris.



GEOLOGICAL DISTRIBUTION OF VOLCANIC CENTRES IN THE BRITISH ISLES
English Miles
0 50 100 150
Upper Kainozoic none
Lower K
Mesozoic none
Permian P
Carboniferous CR
Devonian D
Silurian S
Ordovician O
Cambrian CM
Archean A
Bartholomew Edin.

FIG. 28.

In most British districts, however, the Cambrian rocks were laid down as quiet sediments undisturbed by volcanic action.

The succeeding Ordovician Period was one of intense volcanic activity. Each of its three subdivisions was marked by the piling up of huge volcanoes. In the first of the three subdivisions—the Arenig—a long series of eruptions built up the mountain of Cader Idris; a sheet of volcanic debris formed the Borrowdale slates of the Lake District; and some of the many lavas in southern Scotland flowed down to the sea and there consolidated in the rounded masses known as pillow lavas.

In the middle part of the Ordovician—the Llandeilo Epoch—a volcano was in action at Builth, in Brecknockshire; and in the Upper Ordovician or Bala Epoch volcanic action was renewed with increased vigour. Snowdon was built up around one of the volcanic centres in North Wales. A series of volcanoes were crowded together on the coast of Waterford, and evidence of another area of eruption is preserved in the hills of Kildare.

In striking contrast to the volcanic activity

of the Ordovician Period was the almost complete volcanic quiet of the Siluran. The only established Silurian volcano in the British Isles was on the Dingle promontory in south-western Ireland, where a series of tuffs and lava streams of rhyolite are interbedded with marine deposits. These series of rocks have generally been assigned to the middle part of the Silurian; but according to a recent paper by A. McHenry they should be referred back to the earliest part of the Silurian (*Nature*, February 8, 1912, p. 504). Throughout England and Scotland the Silurian rocks consist of sediments which are mostly marine, and were all laid down without volcanic interruption.

The Devonian Period was marked by the resumption of volcanic action. Most of Devonshire and Cornwall were covered by a sea, whose surface was broken by some volcanic islands. In Scotland and Ireland the Devonian System is represented by Old Red Sandstones which were laid down on land or in fresh waters; these sandstones are associated with many volcanic rocks, including

in the Ochill Hills and the hills of Argyll, flows of andesites which are allied to the lavas of the Andes.

The Carboniferous Period began in England with the deposition of shales and the thick beds of Carboniferous Limestones; but the rocks are occasionally interbedded with layers of volcanic tuff, as in Derbyshire, and they show that there were occasionally volcanic eruptions during this period. Scotland, however, at this time was a centre of intense volcanic activity. The eruptions began with the outpouring of sheets of basalt and allied rocks which formed the lava plateaus of the hills around Glasgow, and in the same period a great volcano built up Arthur's Seat near Edinburgh. Subsequently volcanic action changed its character and built up numerous small scattered volcanic vents. The eruptions continued in Scotland into the Permian Period during which volcanic action was most important in Ayrshire. During the same period some smaller volcanoes were active in Devonshire.

The Permian Period was succeeded by the

Mesozoic Era, and some volcanic rocks in Devonshire were at one time assigned to the Trias, the lowest of the three divisions of the Mesozoic. They have been proved to be of Permian age and there is no trace of volcanic activity during Mesozoic times in any part of the British area.

After the end of the Mesozoic the eruptions burst out anew in Ireland and western Scotland. The exact date during the Kainozoic Era of these eruptions is still doubtful, as the fossil plants found associated with the volcanic rocks do not give evidence. The eruptions began either in the Eocene or Oligocene, and they took place at a series of volcanic centres, around which were built up the plateau of Antrim, and the volcanic masses in the islands of Mull and Skye, and on the peninsula of Ardnamurchan. These great eruptions were probably contemporary with those which laid the foundation of Iceland and covered parts of Greenland with sheets of volcanic rock.

The variations in volcanic intensity during successive geological periods may be ex-

plained as due to the alternation of periods of violent disturbances of the earth's crust with periods of slight and gentle movements. As the earth shrinks in size the crust sags gently downward. For a time the crust may easily accommodate itself to the internal contraction, and volcanic activity is dormant. As the shrinkage proceeds the crust becomes deformed and unstable; and the earth ultimately recovers stability by great readjustments of the surface. During these movements the crust is fractured and parts of it sink, and at such places the pressure on the underlying rock is especially heavy. This extra weight on the superheated plastic rock and the opportunity given for its escape through the fractures occasion fresh periods of volcanic activity.

At one time the view was held that any change in the earth's shape was impossible. The earth was regarded as a true spheroid, and as rigidly confined to that form by its rotation on its axis. If so, the deformations of the earth required by the tetrahedral theory could never have occurred. It is,

however, now admitted that the earth is not exactly a spheroid. It is a geoid—that is to say, the earth has no regular geometrical figure, but is earth-shaped. Its shape appears to be like a badly made peg-top, flat in the Arctic and more pointed at the Antarctic Pole, and with its Equator not exactly a circle. The existence of such irregular deviations from the spheroidal form indicates that other deviations due to irregular elevations or depressions are possible. These deformations are no doubt very small in comparison with the full diameter of the earth; for only the comparatively slight difference of ten or twelve miles in a diameter of nearly 8000 miles separates the level of the highest mountain from that of the deepest sea. A subsidence which is inappreciable in reference to the bulk of the earth would convert a continent into an ocean.

The oceans occupy basins due to subsidences. The continents are composed of areas which have been either directly uplifted or have been left upstanding owing to the sinking of the areas now occupied by the oceans.

The crust of the earth, instead of being rigid, is in constant movement. It is always quivering with slight tremors and undergoing slight elevations and depressions. It appears to undergo slow but frequent changes in its external form, which though slight are important in their total effects. The crust is so unstable that the North Pole wanders about over a small area; and this wobbling of the earth has been regarded as due to unequal loading of the surface by heavy snowfall or rainfall upon one part of the Arctic regions being unbalanced by an equal weight on the other side of the Pole.

Professor Milne recognised by his seismographs the sinking of the western side of Japan after heavy rain. Sir George Darwin observed the subsidence of the bed of the English Channel by the extra weight of water in it at high tide, and its re-elevation on the removal of this load at low tide. Recently Professor Hecker has shown that it is possible to measure the tidal rise and fall of the land under the attraction of the sun and moon.

The earth, owing to the combined influence

of gravity and its rotation, tends to take the form known as a spheroid of revolution (see p. 156), but at present, owing to the instability of its crust, it only approximates to that figure.

It is, therefore, quite admissible to introduce slight changes in the earth's shape to account for the distribution of land and water at different geological periods.

The distribution of ocean and continent in former times is still uncertain, and maps prepared by various authorities show great differences, due chiefly to uncertainty as to the former conditions of what are now the great oceans. We trust that the fossils collected upon their opposite shores will ultimately help to fill these great gaps. For if at any period of the earth's history the land plants and land animals were the same on both sides of the South Atlantic, for example, and these particular organisms did not extend into the Northern Hemisphere, we may reasonably conclude that they passed by a southern land route across the present ocean.

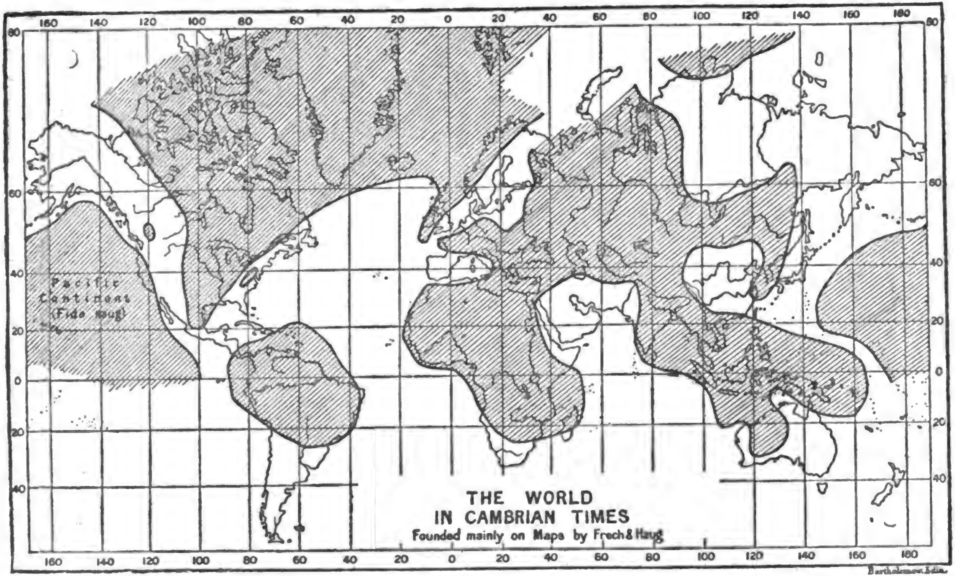


FIG. 29.—(The land is shaded.)

The oldest known period of which we have any appreciable knowledge of life on the earth is the Cambrian, and we find then that the distribution of land and water on the globe greatly resembled that of the present day (Fig. 29). Thus, North America was a great triangular continent tapering southward and washed on both sides by Cambrian seas. Its form was like that of the existing continent, but it was situated somewhat further to the east. Europe consisted then, as now, of a series of peninsulas and seas, but the main mass of the European lands lay further to the east, as it extended from the Baltic into central Asia. The sea which covered part of the British Isles extended eastward to the north of the European continent, and it spread southward again in eastern Siberia. Apparently the great backbone of Asia was already land and included Manchuria and probably a large area in the northern Pacific.

In the Southern Hemisphere, according to Professor Frech, all the northern part of South America was occupied by a Brazilian

island of continental size. Africa was connected north-eastward to Europe and it extended southward to Cape Colony; and it probably tapered to a point in that direction, as some Cambrian fossils are reported from the western coast of southern Africa. Parts of Australia were also land, but much of that continent was covered by a sea of which one arm extended northward into China, and another southward, probably across South Victoria Land and nearly, if not quite, to the South Pole.

The land of the world in Cambrian times appears, therefore, to have consisted of three great northern continents which tapered southward, and of three insular or peninsular continents which extended southward into a great southern sea. The widespread marine deposits in northern Europe, northern Asia and America indicate an Arctic sea at that period, though the North American continent extended across Greenland as far as Spitsbergen; and if there were then an Arctic ocean, as is represented by Haug, but denied by Frech, it lay somewhat to the east of its present position.

The striking resemblances between the distribution of land and water in Cambrian times and in the present would appear to suggest the permanence of the oceans and continents; but examination of the plan of the earth in subsequent periods shows fundamental differences in the distribution.

On the tetrahedral theory the chief changes in the arrangement of ocean and continent should be due to movements along two series of lines. We should expect the lands that extend north and south along the vertical tetrahedral edges to be often present, and to show signs of great earth movements along lines approximately one-third of the distance around the globe apart. But as the earth by the shrinkage of its raised edges recovers its spheroidal form, long belts of land and sea would naturally be developed along lines running east and west. With a new period of shrinkage the tetrahedral plan of the continents would be again established; but the polar depression need not always be at the northern Pole. When there is an ocean at one Pole there should be a

continent at the other; but it would be quite possible to have a South Polar ocean and an Arctic continent owing to the tetrahedral collapse taking place around the South Pole instead of around the North. The positions of the vertical tetrahedral edges should be fairly constant; but the three edges around the polar depression might develop sometimes in the Northern and at others in the Southern Hemisphere.

The evidence as to the former distributions of land and water are consistent with these expectations. Thus, passing from the Cambrian to later periods, there is a great change in the arrangement of land and water. How complete these changes are may be shown by comparison of the maps of North America in the Cambrian (Fig. 30) and in the Silurian (Fig. 31) periods copied from the recent series of palæographical maps by Mr. Bailey Willis.[1]

The North American continent of Cam-

[1] *Outlines of Geologic History, with Especial Reference to North America.* A series of essays organised by Bailey Willis; edited by Rollin D. Salisbury. Chicago: 1910.

brian times has disappeared almost completely in the Silurian Period.

Changes in other parts of the world are no

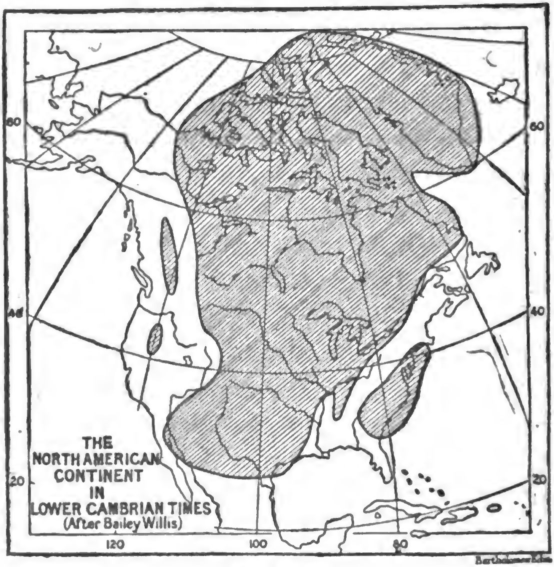


FIG. 30.

less important. Thus, Professor Frech's map of the world at the beginning of the Ordovician Period shows (Fig. 32) an almost complete reversal of land and water between the

Northern and Southern Hemispheres, as compared with the present plan. There was a great Arctic continent and an Antarctic

Fig. 31.

ocean. North America was covered by the sea with the exception of an "Algonkian peninsula," and land antipodal to this sea covered all the Indian Ocean and connected

northern Australia and Africa. The shape of South America, according to Frech, was strikingly like that of the existing continent only inverted; it tapered northward and was connected by the narrow Algonkian peninsula to Greenland.

In two respects Frech's map seems to require amendment. Thus, there is weighty evidence to show that the southern part of the South American continent, the boundary of which Frech marks as doubtful, should be extended both westward and eastward. Also there was a great land in Manchuria which probably extended southward and was connected with the lands to the north of Australia; and this North Pacific land would have been antipodal to the sea that then existed in the South Atlantic. If these two modifications be made then the world in the beginning of the Ordovician had a tetrahedral symmetry, but the relative positions of land and water in the Northern and Southern Hemispheres were reversed.

In Upper Palæozoic times, at the end of

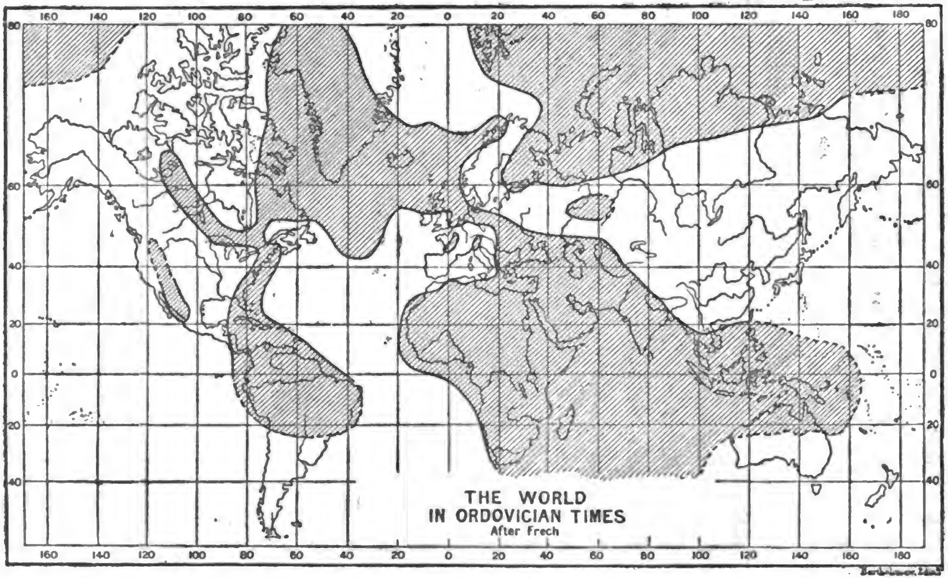


FIG. 32.—(The land is shaded.)

the Carboniferous Period and at beginning of the Permian, there is even clearer evidence of the recurrence of the Lower Ordovician arrangement. For a continent extended east and west across the Southern Hemisphere from Australia through India and Africa to South America, most of which was included. This great east and west continent is known as Gondwanaland, from the Gondwana beds of India. This land was characterised by a special vegetation which is known as the Glossopteris Flora, after its most typical plant. Glossopteris was a fern or fern-like plant with large blunt leaves, each of which has a prominent midrib (Fig. 33). The leaf somewhat resembles that of our Hart's Tongue Fern. The plant grew from a creeping underground stem or "rhizome," which was long regarded as a distinct plant and was named Vertebraria (Fig. 34).

This Glossopteris Flora ranged from Australia through India to Russia and through Africa to Brazil (Fig. 35). Except in Russia it has not been found in the northern lands, which were occupied at the same time by a

distinct flora. This northern vegetation was characterised by the great tree ferns and

FIG. 33.—A leaf of glossopteris.

FIG. 34.—Vertebraria—the underground root of glossopteris.

giant horsetails (Calamites) which supplied the material for our coal seams. These northern plants are not found in the Southern Hemisphere, except that they extended along Africa to an isolated colony at Tete on the Zambesi in Portuguese East Africa (Fig. 35T), where some of the northern plants lived in association with Glossopteris and thus proved that the two floras were contemporary.

Gondwanaland appears to have been isolated from North America, which then extended northward to join the Arctic continent; and according to Frech there was at the same time a South Polar ocean. Gondwanaland projected northward, from a base between Africa and India, into eastern Europe, for the plants of that date characteristic of the Southern Hemisphere, spread apparently there alone, into the north temperate zone. North of Australia there was a great continent which extended southward from the Arctic continent into China; and a third land of this period covered the northern part of the British Isles and Scandinavia.

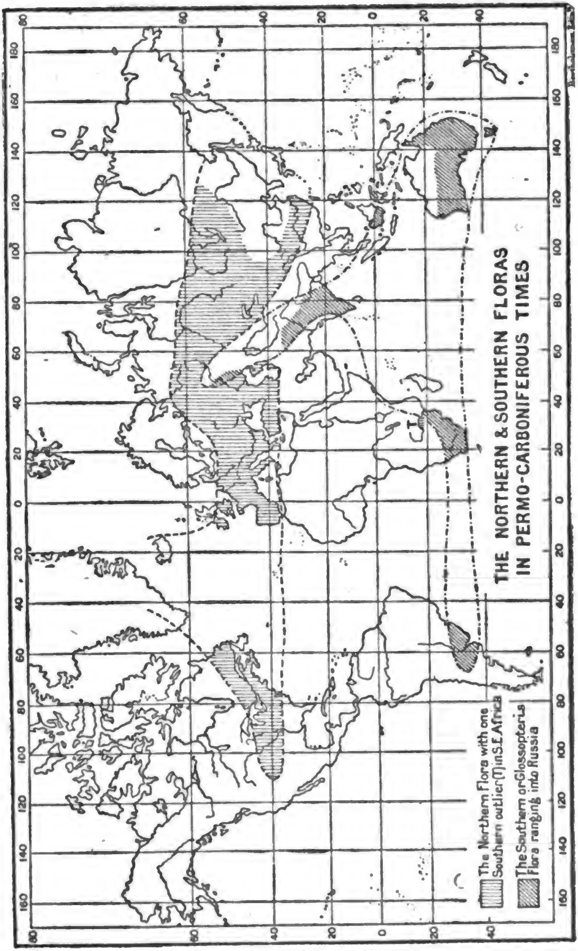

THE NORTHERN & SOUTHERN FLORAS
IN PERMO-CARBONIFEROUS TIMES
The Northern Flora with one Southern outlier (T) in S.E. Africa
The Southern or Glossopteris Flora ranging into Russia

Fig. 35.

Subsequently, in the middle period of the earth's history, the Mesozoic, the interchange between land and sea, can be recognised as due not to local uplifts and depressions, but to world-wide movements of advance and retreat of the sea, which have been established by Professor Suess.

Thus the great continents that existed at the beginning of the Mesozoic Era were slowly submerged by successive advances of the sea, which took place simultaneously in many parts of the world. The simplest explanation of these periodic expansions of the sea is the slow uplift of the sea floor causing the shallowing of the ocean basins. The most important events in the history of the earth during the Mesozoic Era were the repeated shallowing of the ocean basins and consequent great extension in the area of the sea; and these events were probably due to the restoration of the spheroidal form of the earth from the tetrahedral deformation at the end of the Palæozoic Era.

The slow, quiet movements throughout the Mesozoic Era terminated with a fresh out-

break of violent disturbances. It was probably during this period that the North Atlantic and the Arctic Oceans were formed by the sinking of blocks of the earth's crust; and these movements were accompanied by powerful volcanic eruptions along the intervening area from Greenland to Scotland.

Then, after another period of comparative quiescence, followed the last of the great periods of mountain formation—the Miocene,[1] during which widespread fold movements raised the Alps and the Himalaya and the other mountains connected with them. Movements of the same period but of a different type formed the Western Mountains of North America and the Andes in South America, and the great mountain chain of which the fragments from Japan to New Zealand remain as the island festoons along the western shore of the Pacific.

[1] These mountain-building movements continued into the next period, the Pliocene.

CHAPTER XI

THE GEOGRAPHICAL ELEMENTS IN THE EXISTING CONTINENTS AND OCEANS

THE distribution of land and water on the earth is the result of the arrangement of various elevated and depressed areas of land, which are known as the "land-forms." These land-forms are due to the combined effect of denudation and deposition on the surface and to earth movements caused by underground forces.

The land-forms are divided into three "positive land-forms"—mountains including hills, plateaus, and plains—and two "negative land-forms," which exist as hollows between the positive land-forms. The negative land-forms include valleys which are long and narrow, and basins which are very wide or are wide in proportion to their length. Most valleys are cut by denudation and are

valleys of excavation; others are formed by faulting, and they are known as rift valleys.

The various types of land-forms may be illustrated by Figure 36.

The different land-forms were at first attributed mainly to earth movements and earthquakes. So soon, however, as geologists carefully observed the processes at work upon

FIG. 36.—The land forms.

the earth's surface it was recognised that the effects of the quiet but restless processes of denudation are often greater than the geographical features due to deep-seated causes. The explosion of the volcano of Tararewa in New Zealand in 1886 formed a valley nine miles long in the course of a few hours. Chasms formed by such dramatic geographical incidents are less important, even in such volcanic countries as New Zealand, than gorges formed by the slow excavating action of rivers. It is therefore not surprising that

with the spread of closer observation, all the main features in the relief of the earth's crust should have been attributed to denudation. They were usually regarded as due solely to carving by external agents, while the earth itself remained as inert as a block of marble in the hand of the sculptor. There is, however, abundant geological and geographical evidence that the greatest features on the earth's crust are due to internal causes. The agents of denudation merely polish and mould the features which are caused by earth movements.

The existing continents are the result of a complex series of movements of elevation and depression. The main axes of elevation and the position of the chief oceanic basins are determined by the mechanical conditions which dispose most easily of the excess of crust, when it becomes too large; the details of the shape of land and water vary with the structure of the land-forms.

The lands of the world are built on three main types of structure—massive raised blocks, crumpled bands, and wide spread-sheets of sediments.

The massive earth-blocks are the oldest geographical units; they either consist wholly or have a wide foundation of very ancient rocks, and they have stood above sea level throughout all geological time. They are areas of permanent elevation. They have been named the earth's coigns—a word used in crystallography for the projecting corners of a crystal. The coigns include Scandinavia, Labrador, the peninsular part of India, most of western Australia, the highlands of eastern Brazil and much of tropical Africa.

In addition to these major coigns there are many smaller blocks of ancient rocks, which appear to have been areas of comparative stability and to have acted as secondary coigns.

The crumpled bands are more widely distributed. In the earliest geological period, crumpling was probably universal over the earth; but it soon became restricted to special bands owing to the thickening of the crust. The vertical movement of blocks of the crust has gradually become more important than the horizontal crumpling, and has determined the character of wider regions on the earth's surface.

The crumpled bands are now in two conditions, dependent mainly on age. The later fold-mountains are in long continuous bands. The older fold-mountains have been broken up and remain as scattered highlands often surrounded by plains of younger sediments. Thus fragments of the older mountain systems form the hills of Brittany and Cornwall, the Ardennes, the Central Plateau of France, the Harz and other mountains which rise above the German plain, the plateau of Bohemia, and the Appalachian Mountains in the United States.

The most important of the recently folded bands on the earth is that of the Alpine-Himalayan Mountain System, which traverses Europe and Asia along a line from east to west. It was due to the southern part of the north-temperate belt being thrust northward against the northern part. The course of the folded mountain band is very sinuous, as the folds were kept back in some places by the resistance of massive blocks of rock which were so strong that they resisted folding. These stubborn masses have been named by

Professor Suess geological forelands, because they kept back the great earth waves, as the forelands along a coast keep back the waves of the sea. It is these forelands that form the foundation stones of the continent, and between them the folds flowed northward as into bays.

The second band of modern earth-folding surrounds the Pacific Ocean, and its earth movements happened at approximately the same time as those which formed the Alps and Himalaya. The Circum-pacific fold-mountains probably formed a complete girdle around the Pacific Ocean; there is a wide unknown gap on the Antarctic side, but the evidence from Graham Land suggests that the southern shore of the Pacific had the same structure as the eastern and western. The Circum-pacific folds were due to pressure from the lands toward the Pacific, but they were accompanied, or perhaps caused, by the subsidence of its floor. The land waves thus rolled toward the sunken area.

The essential differences between the Alpine and Circum-pacific mountains is that

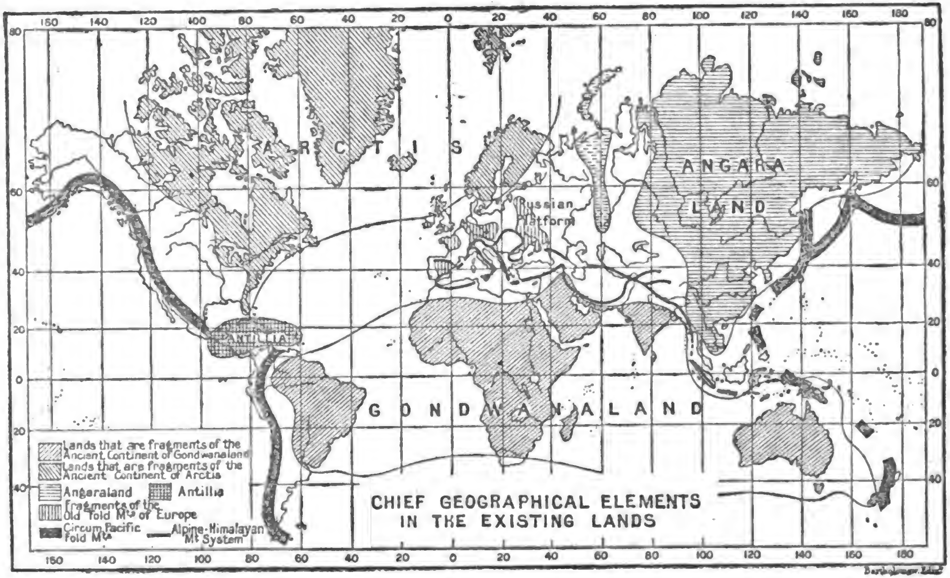
the Alpine waves broke against chains of rocky forelands, whereas those around the Pacific advanced freely. The Alpine waves were due to pressure from the land behind, whereas the Circum-pacific were due to, or accompanied by, the collapse of the area in front. Subsidences were far more important in the case of the Pacific than of the Alpine mountains, and the subsidences in the former were in front of the mountains. In the Alpine lines they were often behind it.

Connected with these differences is the difference in volcanic activity. There were no volcanoes on the Alps, though there were numerous volcanic outbreaks in the basins formed by the subsidences behind the main Alpine line, and there were scattered volcanic fields in front of it. The only places where volcanoes occur in the mountains of the Alpine system itself is where, as in the Caucasus, the mountain line has been broken across by subsequent fractures. In striking contrast with this arrangement, the chief volcanoes of the Circum-pacific mountains are on its heights, such as the great volcanic

groups scattered along the Andes, the great lava fields on the western mountains of North America, some of the volcanoes of Japan, and those upon the plateaus in the North Island of New Zealand. The volcanoes occur less often along the shore, as in the Aleutian Islands, and on Banks Peninsula and at Dunedin in New Zealand.

In the New World the Circum-pacific mountains consist of the Western Mountains of North America extending from Alaska into Mexico; in South America they consist of the Andes, which range from Venezuela to Patagonia. On the western side of the Pacific this corresponding mountain line has been broken into fragments, which form a chain of islands from Japan to New Zealand.

The interspaces between the coigns or great blocks of ancient rocks and the folded belts are often occupied by wide plains of comparatively young sedimentary rocks; the frequent interchange between land and sea in these areas causes the great changes in the range and shape of the continents.



ARCTIS
ANGARA LAND
Russian Platform
ANTILLIA
GONDWANALAND
Lands that are fragments of the Ancient Continent of Gondwanaland
Lands that are fragments of the Ancient Continent of Arctis
Angaraland
Antillia
Fragments of the Old Fold M^ts of Europe
Circum Pacific Fold M^ts
Alpine-Himalayan M^t System
CHIEF GEOGRAPHICAL ELEMENTS IN THE EXISTING LANDS

FIG. 37.

Each of the continents (Fig. 37) is built up therefore of these three types of materials, the ancient blocks which are fragments of older lands, the younger fold mountains, and the interfillings of sediments.

In Europe, the north-western corner, including Finland, Scandinavia, most of Scotland and part of northern Ireland, consists of a number of blocks of very ancient rocks; and these blocks are all fragments of the old continent of Arctis, which once extended westward and included the eastern part of North America and Greenland, and often Spitsbergen. The whole of this land was not necessarily above sea level at the same time; but most of it has been very often land, and some parts of it have probably never been submerged by the sea.

The second element in the structure of Europe includes all the mountains of the Alpine System:—the Pyrenees, the Alps, the Carpathians and the Balkans; they once continued across the Black Sea and joined the Caucasus. From this main Alpine band two loops branched off to the south. One

of the loops crossed the western Mediterranean and passed through the Balearic Islands to the Sierra Nevada of southern Spain; it then bent back across northern Africa through the Atlas Mountains and across Sicily and along the Apennines through Italy to the Alps. The second loop is formed by the mountains on the western side of the Balkan Peninsula, and, like the Pyrenees, it was somewhat earlier in date than the main Alpine movements.

The irregular course of the Alpine mountains across Europe was due to the resistance of some massive earth blocks which resisted crumpling and kept back the Alpine line in front of them. The chief of them are the Meseta or main plateau of Spain, the Central Plateau of France, the Black Forest in Germany, Bohemia, and the area known as the Russian Platform in south-western Russia.

The rest of Europe is composed mainly of sheets of sediment spread out in level plains or gently undulating hills. These sheets form the great European Plain, the plains in the basins of Hungary and Lombardy on

the inner side of the Alpine folds. The plains are interrupted occasionally by fragments of older mountain systems (the secondary coigns), as in the Ardennes of Belgium, the hills of Brittany, Cornwall and the south of Ireland.

Asia, though now widely linked to Europe, was separated from it in early Kainozoic times by a sea which connected the Arctic and Indian Oceans across eastern Russia and Persia. Asia consists of four main elements. They are the remains of an ancient continent, the Angaraland of Professor Suess, which forms most of north-eastern Asia, and was connected with the ancient plateau of southern China. To the east of Angaraland are the large plains of western Siberia. To the south of both these units are the fold-mountains of the Alpine System, some of which have broken across part of Angaraland. The main line extends from the Caucasus to the Himalaya. As in Europe, there is a series of loops on the southern side; the westernmost of them leads from the south of the Caucasus through Persia and across

Beluchistan to the Suleiman Mountains; through them it goes northward to rejoin the main chain in the mountain knot of the Pamir. Thence the main line continues eastward through the Himalaya until the resistance of the Chinese plateau has forced it southward, and part of it now lies beneath the Bay of Bengal; it reappears in Sumatra and continues through Java and across the Malay Archipelago. Further east it may join with the contemporary Circum-pacific mountains in New Guinea.

To the south of the Himalayan Mountain System there are two ancient plateaus—Arabia and the peninsula of India—which are remnants of the former continent of Gondwanaland. Of this dismembered continent Australia and most of Africa are both great fragments.

Africa includes two other elements; for the Atlas Mountains in Northern Africa belong essentially to Europe, and though southern Cape Colony was once joined to Gondwanaland, it is part of the edge of a foundered land which once lay further to the south.

North America consists of two ancient mountain masses, one in the eastern and the other on the western side of the continent. The eastern is the larger; it was the western part of Arctis, from which the region of the Appalachian Mountains and the eastern coast lands of the United States repeatedly projected as a southern peninsula. To the west of the continent was an ancient land which included the site of the Rocky Mountains; at various periods it extended southward into Mexico and north-westward into Alaska. Between these western and eastern lands, the sea has repeatedly extended northward from the Gulf of Mexico to the Arctic Ocean. The formation of North America has been due to the filling up of this inland sea by the deposition of sediments. The eastern and western lands have thus been united, while they have been narrowed by the foundering beneath the Atlantic and the Pacific of their former eastward and westward extensions.

To the south of the United States are the remains of an ancient land known as Antillia, as it included the area of the Antilles.

This continent was in existence a little before the deposition of our chalk, and has been gradually destroyed by repeated subsidences.

In South America the largest single element is that which forms the highlands of Brazil and of Guiana; it is the westernmost fragment of the ancient continent of Gondwanaland. Along the western coasts in Chili and Peru there are some very ancient rocks exposed at the foot of the Andes, and they, with the sedimentary materials to the east of them, indicate the former extension of the land westward into the Pacific. For some of the sedimentary rocks in the Andes near the western coast consist of beds of pebbles, which become smaller and pass into sands further to the east, showing that the source of these materials was land to the west of the present coast of Chile.[1]

Of the oceans of the world, the one of which we have fullest information concerning its geological history is the sea which Professor Suess has called the Tethys. It was an inland sea which extended east and

[1] *Vide* Burckhardt, *Rev. Museo de la Plata*, vol. x, 1902, pp. 177–192.

west from the West Indies between northern Europe and Africa, and across Asia to the Pacific. It was bounded to the north by the continents of Arctis and Angaraland and to the south by Gondwanaland and the relics which have survived from it.

The Mediterranean and the seas of the West Indies are the last remnants from this Tethys. The original basin has been greatly diminished in size, but the Tethys has gained in return by giving birth to the Atlantic Ocean. The Atlantic has been formed by two gulfs which extended north and south from the Tethys, and they by repeated enlargements, due to a foundering of the coastlands, have developed into the Atlantic.

The age of the Pacific is much less certain. The widespread range of marine rocks of the age of our New Red Sandstone suggest that the Pacific may date from the Tuas, but its close connection with the Circum-pacific mountains, which are of Kainozoic age, suggests that it has existed in its present form only from the date of the elevation of the mountain chains that rise around its shores.

PART IV

THE SHARE OF LIFE IN THE PREPARATION OF THE EARTH

CHAPTER XII

THE BIOSPHERE

The earth during its making has passed through four main stages. First, the consolidation of the metallic meteorites into the solid globe; second, the separation of the stony crust from its metallic core; third, the condensation on to the surface of the earth of the waters in the oceans; and fourth, the buckling of the surface into the elevations which form the lands, and into the great basins which contain the oceans. The land and water were thus separated by deformation of the earth's crust.

The earth, however, at the end of these stages was still incomplete, for it would have been unfit for occupation by man. It still

required such changes on the earth's surface as rendered the existence and development of life possible upon it, and the prolonged action of the lower kinds of animals and plants in the preparation of the earth for human occupation. Organic remains have added so much to the materials on the floors of the sea and in the surface layers on the land that Walther has suggested that in addition to the four usually accepted zones of the earth, the barysphere, lithosphere, hydrosphere and atmosphere—a separate zone, the biosphere, should be established for the layer in which the products of animals and plants are the most important constituents.

The occupation of the earth by the higher animals and plants required a preliminary chemical and physical preparation of its surface, so that the lower forms of life could exist and gradually prepare the materials necessary to the more highly developed organisms. The existence of life on land required the breaking up of the surface by the various chemical and physical agents; they convert the upper layer of both primary

and secondary rocks into the loose decayed material known as the soil.

Both land-animals and land-plants are dependent for their subsistence upon the soil. The animals are dependent for their food on the materials formed by plants. The higher plants can only grow where the surface is covered by a layer of loose material, into which they can thrust their roots and so anchor themselves to the ground. Some of the loose material in the soil, moreover, must have undergone such thorough decay that the plant-food in it is soluble and can be removed by the water in the soil and thus nourish the vegetation.

Rocks are broken down into soil by the attack of all the atmospheric agents. In most quarries the fresh hard rock can be seen to pass gradually upward into a band of broken waste rock, which is too decayed to be of use as building stone; it is known as the subsoil, and its lower limit is usually marked by the depth reached by the plant and tree roots. The subsoil passes upward into the soil, which is a layer of completely

decayed material, coloured brown by the organic matter, and lying immediately beneath the surface.

The chief agents in the formation of the soil are the moisture and the gases of the atmosphere. Water in the soil is charged with acid gases, and as it soaks into the rocks it dissolves out some of their constituents. If the ground should freeze at night the water in the pores of the stones expands suddenly as it is turned into ice, and thus helps to break them into powder. The water, moreover, combines chemically with some of the constituents of the rocks, and the expansion due to this chemical change also helps their disintegration.

The two chief gases in the atmosphere which attack the rocks are oxygen and carbon dioxide (CO_2). The carbon dioxide is the more important in this connection. It unites with various earths and alkalies to form the carbonates, of which the most important is carbonate of lime.

The essential constituents in the tissues of both animals and plants are complex com-

pounds composed of the elements carbon, oxygen, nitrogen and hydrogen, and all four elements exist in the atmosphere. Plants are largely composed of water and of compounds containing carbon, which is extracted from the carbon dioxide in the air. This gas is decomposed in the plants, and the carbon is fixed in the vegetable tissues as some complex carbon compound. The nitrogen, which is essential for the food of animals and ordinary plants, is first obtained from the atmosphere or from the air in the soil, by the action of the primitive organisms known as bacteria; most plants obtain their nitrogen from nitrogenous compounds present in the soil. The nitrogen is then converted by the plant into products which animals can use as food.

Animals are therefore dependent on plants for their nitrogenous foods; but in return they help to enrich the soil with nitrogenous materials. Thus worms and burrowing animals working through the soil continually fertilise it with their excrement, and also with their bodies after death.

The soil is therefore the factory in which, directly or indirectly through the plants above it, the nitrogen and carbonic dioxide of the atmosphere are converted into materials which can be used as food by animals.

The soil is also all important as a purifying agent. The decomposition of organic materials on the earth's surface gives rise to poisonous materials and nourishes injurious germs which cause disease. If these germs sink underground they may multiply rapidly owing to the warmth and darkness, and may spread and contaminate the water supply of a large district. The soil, however, acts as a filter, and as water percolates through the living mould the injurious organic materials are attacked and rendered innocuous. Hence if polluted water percolates down through a soil into subterranean reservoirs of drinking water, the germs are destroyed on the way. The rain is thus purified and added to the underground supplies of water in a condition safe for use.

The soil is therefore our ultimate source of food supply and the universal scavenger,

which keeps the surface of the earth clean and protects our well water from pollution. The soil, however, requires constant re-fertilisation. Its soluble food constituents are continually being removed and carried to the sea by rivers; and in time the soil would become exhausted and barren. Many of the secondary rocks are very poor in plant foods, in which the primary rocks are usually much richer. The most important mineral plant foods are the alkalies, soda and potash, the earth calcium, and a few other elements such as phosphorus and sulphur. Most of these materials are contained in the deep-seated primary rocks. The great disturbances of the earth's crust which built up the mountains of the world have lifted the primary rocks above the surface, so that they are subject to the attack of the atmospheric agencies. The constituents valuable as the food of plants are washed down the hillsides and re-fertilise the soils of the lowlands, where the climatic conditions are most favourable for agriculture.

Volcanoes also play an important part in

raising deep-seated rocks rich in lime, phosphorus, and alkalies above the earth's surface. Volcanic dust is carried far and wide by the wind; the volcanic rocks themselves decay under the action of rain and atmosphere, and the debris is washed down the sides of the volcano and spread over the lower slopes and there forms the extremely fertile soils for which old volcanic lands are famous.

CHAPTER XIII

PROTOBION—THE FIRST LIFE ON THE EARTH

THE soil requires, however, not only enrichment by inorganic substances, but also by various organic constituents, such as the nitrogenous materials produced by bacteria or introduced by worms. A soil obtains the materials useful to the higher forms of life from the products of lower types. The development of the higher animals is possible only owing to the prolonged previous activity of the more primitive forms of life. How life originally appeared upon the earth is a question to which the only answers now possible are little more than indefinite suggestions. Lord Kelvin maintained that life may have come to the earth as a spore borne by a meteorite from some other world. This is certainly a possible explanation of the arrival of life upon our earth; for spores may retain their vitality for prolonged periods,

and can survive exposure to the most intense cold. Hence if a world were shattered by the disruptive approach of another heavenly body some of the fragments might carry with them germs which might retain their vitality even during a long journey through the intense cold of outer space. The most serious danger to the germ would be that of being burnt when the meteorite is heated by friction with the earth's atmosphere; but if the spore lay in a deep crack it might remain quite cold although the surface of the meteorite were rendered white hot; for the heat due to friction with the atmosphere is only sufficient to fuse a very thin skin on the surface of a large meteorite. The interior remains intensely cold. Nevertheless, Lord Kelvin's hypothesis only purposes to explain the distribution of life through the universe and not its origin.

The same objection applies to the theory of Professor Svante Arrhenius, who has suggested that living matter could pass from star to star without the intervention of a meteorite to serve as the ferry. He claims

that some of the smallest spores could be carried at a comparatively high speed from one world to another by "light pressure." The impact of rays of light falling upon a thin body presses it backward. This fact is well known from the radiometer, a familiar exhibit in the shop windows of scientific instrument makers. It consists of four arms with very thin vanes mounted on a pivot in a vacuum; the arms revolve when exposed to the action of strong sunlight. Similarly the pressure of the waves of light upon a minute spore would, according to Professor Arrhenius' calculations, be sufficient to drive it through the atmosphere and so on to some distant sphere.

Both Lord Kelvin and Professor Arrhenius' theories only transfer the problem of the origin of life to some other sphere; and the conditions on the early earth appear to have been as suitable for the first development of life as any that we can reasonably assume to have existed elsewhere. Hence it is probable that the life of the earth is one of its own products.

The production of living from non-living material has, however, been regarded by many authorities as inconceivable. They consider that the organic and inorganic worlds [1] are separated by such an impassable barrier that the origin of life must be attributed to a direct act of creation. However great the difference between the living and the dead, the distinction is very difficult to define. That difficulty alone suggests that the separation between the living and non-living is not so absolute as has been often represented. The ordinary definitions in the dictionaries explain life as the act of living, as the "vital force," or as the difference between living and non-living matter. Such statements assume the difference they make no real effort to define. Webster's Dictionary (1907 edition) makes one of the

[1] It should be borne in mind that the term organic is used with two different meanings. Organic usually means connected with or formed by life; an organic product is one formed by living agencies. In chemical nomenclature, on the other hand, an organic substance is one containing carbon. A carbon compound formed artificially, or synthetically, to use the term adopted in chemistry, is therefore organic in the chemical sense of the term, but inorganic in its ordinary sense. There is, fortunately, a tendency for chemists to abandon their special use of the term organic.

most serious attempts at a definition. Life, it says, is "The potential principle, or force, by which the organs of animals and plants are started and continued in the performance of their several and co-operative functions; the vital force, whether regarded as physical or spiritual." That definition, however, merely asserts that life is the living force of animals and plants, and in its answer repeats the term it endeavours to explain.

The attempted definitions of life have proved remarkably unsuccessful. Professor Judd, in his Presidential Address to the Geological Society in 1887, quoted the definitions of two leading biological philosophers, George Henry Lewes and Herbert Spencer. George Henry Lewes' definition is written in the simpler language. It says, "Life is a series of definite and successive changes, both of structure and composition, which take place in an individual without changing its identity." According to Spencer's more technical language life is "the definite combination of heterogeneous changes, both simultaneous and successive, in correspond-

ence with external co-existences and sequences." Professor Judd showed that both these definitions are also applicable to the force that controls the growth of crystals. The development of complex crystals takes place by a series of definite and successive changes both in structure and composition which take place without altering the identity of the crystal. Thus, to take a simple case, a single crystal of felspar when tested by suitable optical methods may be found to consist of a series of zones which have been built up one around the other. The successive zones differ in composition; and in consequence of this difference they vary also in molecular structure. The central part of the crystal may so react on polarised light that it is said to have a high angle of extinction. This angle of extinction becomes smaller in the successive outer zones until in the outermost the angle of extinction may be reduced to nothing. This optical test is accepted as proof that the proportion of lime present in the crystal decreases from the centre to the margin. The "vitality" of

the crystal has enabled it to undergo a long series of changes in structure and composition without altering its identity. It is one individual crystal. It may subsequently be so completely altered that it may be broken up into a mosaic of other minerals, and yet the crystal retains its external form and its identity. The history of such a crystal, to use Herbert Spencer's language, is that of a series of heterogeneous changes, both simultaneous and successive, in correspondence with external coincidences and sequences; and the force which has controlled the growth of that crystal would therefore answer to his definition of vitality.

The processes of crystal formation may in fact be claimed as one of the simpler phases of vital phenomena. "'Life!' 'Vitality!'" exclaims Professor Judd. "These terms are but convenient cloaks of our ignorance of the somewhat complicated series of purely physical processes going on within plants and animals. 'Organisation!' Why should the term be applied to the molecular structure of an Amœba or a yeast cell, and refused to that of a crystal?"

Professor Huxley had earlier asserted that vitality was only the name used for a series of complex physical processes; and Professor Judd's view has been often re-expressed. According to Professor Meldola, "The doctrine of a special 'vital force' has received its deathblow at the hands of modern science." [1] The term petroplasm, analogous to protoplasm, has been invented for what Professor Judd called the vitality of minerals.[2]

As the definitions of the term life are not very instructive, the essential nature of life

[1] Raphael Meldola, *The Chemical Synthesis of Vital Products*, vol. i, 1904, p. vi. Professor Meldola, in the remainder of the above sentence, refers to the still unknown modes of chemical action by which organisms build up the products which chemists prepare by other processes.

[2] Professor F. R. Japp, in his presidential address to the Chemical Section of the British Association at Bristol, in 1898, has advocated the distinction between living and dead matter which was proposed by Pasteur. Pasteur, in 1860, declared that he knew of no "more profound distinction between the products formed under the influence of life and of others" than the absence from the latter of what is known as molecular asymmetry. But asymmetric compounds were prepared artificially in the very year in which Pasteur announced this view. According to Professor Japp, however, non-vital matter can only form asymmetric compounds in opposite pairs. Thus, living material forms structures all of which may have a right-handed pattern; but he claimed that inorganic material must produce both right-handed and the corresponding left-handed structures at the same time. An interesting discussion in *Nature* (vols. 58 and 59) followed this address, and the distinction proposed was broken down.

can be better obtained from a list of its essential processes. Professor W. A. Osborne, in his *The Elements of Animal Physiology*, 1909, pp. 9–15, enumerates six essential processes of life. They are—

1. Renewal and repair.
2. Absorption of energy and performance of work.
3. Power of response to changes in the environment.
4. Self-defence from other organisms.
5. Growth and reproduction.
6. Memory and intelligence.

All of these processes are no doubt essential to existing life, but it is quite possible to conceive of conditions on the early earth when they were not all essential. The first living being had no need of self-defence from other organisms. It started without a memory, while, as Professor Judd has shown, the memory of crystals is far more retentive than that of any organism. Further, life would probably have begun at a time when the earth had a dense atmosphere heavily laden with carbon dioxide and thick with water

vapour, so that on the earth's surface there may have been no appreciable change of environment. Even at the present time life on the earth exists in some places where the conditions never change from year to year, as in deep dark caves or on the floor of the oceanic abysses.

The earliest forms of life may have lived under conditions of such uniformity that only three processes were essential to their existence. The first was the absorption of material as food and the rejection of the waste products; but this, it should be remembered, is a process which organisms share with minerals; for crystals also have the power of extracting from solutions the molecules they can use as food and of either leaving the rest untouched or at once redepositing them. Such mineral excreta are seen in many crystals as included grains of foreign matter.

It may, however, be represented that organisms grow by absorbing food internally, whereas minerals grow by the addition of material on the outside. To use the tech-

nical terms, organisms increase by intussusception, while minerals and crystals grow by accretion, *i. e.* the addition of external layers. It has been often held that this difference is a definite distinction between living and dead matter. Some inorganic bodies, however, grow by intussusception; and they may develop into plant-like forms in obedience to the same external influences as mould the shapes of plants. The plant-like growth of some inorganic materials has been well illustrated by the experiments of Mons. S. Leduc. He prepared seed-like grains from one-twenty-fifth to one-twelfth of an inch in diameter, composed of two parts of sugar mixed with one of sulphate of copper. He then sowed these grains in water containing from one to four per cent. of gelatine, one to ten per cent. of common salt, and two to four per cent. of ferrocyanide of potassium. The sulphate of copper reacts with the ferrocyanide of potassium and forms a membrane of ferrocyanide of copper through which water can pass while sugar cannot. Accordingly there is a constant entrance of water

into the grain, where it dissolves the sugar. The grain accordingly begins to grow. Small buds project from the grain, and they increase in length because the membrane yields to the internal pressure more readily at the thin tip than on the sides. The bud-like projections therefore grow into cylindrical stems. The bending of the stem or some other cause may form a weak point on the side, and a branch will grow out from that point; and thus the stems develop into plant-like tufts. If the stems reach the surface of the water they can grow no longer upward; further growth takes place on the sides and produces a thin sheet which spreads over the water like the floating leaves of a water lily. Such a structure, with its seed, stems and leaves, is purely inorganic in nature; but it has grown by intussusception, and purely mechanical influences have guided it in its imitation of complex vegetable growths.

The second property characteristic of life is the power of absorbing from food a supply of energy and the power to do work. Organisms obtain their supplies of energy by break-

ing down complex unstable compounds and converting them into simpler and more stable materials. Inorganic materials can also absorb energy by purely physical processes such as the absorption of latent heat by melting ice; and physical processes set free energy, as in the combustion of a piece of coal.

The third property is the capacity to continue the two first operations and to transmit the power to do them to the separate parts of the mass after its increase in bulk has rendered division necessary. The living organism is not only able to divide into smaller bodies, but it can transmit to them its power to derive energy from suitable foods and to divide again. This third process is also common to inorganic matter, for during the consolidation of rocks the crystals soon reach a size beyond which they do not grow. Fresh material may be deposited upon the surface of an already formed crystal; but it grows into separate crystals, which may increase until they reach the size of those of the preceding generation. There would seem at first sight no reason why

crystals in a vast subterranean reservoir of molten rock should not grow to gigantic size. Some of the early geologists, failing to distinguish between slaty and crystalline cleavage, regarded the whole mountain of Skiddaw in the Lake District as one great crystal of slate. But the largest known crystals (beryls) are only between two and three tons in weight, and such giants are very exceptional. Even where a thick bed of rock has become crystalline its constituent minerals are generally quite small in size. The average size of the crystals is usually only a fraction of an inch, and in most rocks the crystals are not more than an inch or so in diameter. Crystals soon reach a limit in size, and the deposition of the material continues in successive generations of small crystals. All the crystals have the same general properties, and the younger generations grow on the same lines as their predecessors.

Hence all the three processes that are essential to the simplest forms of living matter are also shared by crystals.

What, then, is the difference between organic and inorganic matter? The original difference was, perhaps, only one of chemical composition. The ordinary minerals are composed of silicates and earthy materials. The organic bodies are composed, on the other hand, of the elements carbon, oxygen, hydrogen, chlorine, sulphur, phosphorus, sodium, potassium, iron, magnesium and calcium. The largest proportion consists of the carbon, hydrogen and oxygen; the other essential elements are present in comparatively small quantities. The first formed organic matter was probably composed essentially of only carbon, hydrogen and oxygen; it would have been soft and plastic; and when mixed with some water had the texture of a jelly.

The problem of the origin of life is that of the formation of quantities of carbonaceous jelly under such conditions that it would have continued to increase until the masses mechanically subdivided, and the separate parts would inherit the power to grow and subdivide in turn. The problem is that of

the formation of a self-generating, reproductive, carbonaceous jelly, of such a nature that it served as the beginning of the whole of the organic evolution that followed.

On the early earth the conditions were probably such as to have started these processes on some inorganic matter. The surface of the earth was warm and moist, and owing to the thickness and density of the atmosphere, its constant clouds and possibly its higher proportion of carbonic acid, the environment on the surface underwent probably but little change; and the temperature was probably almost the same night and day all the year round. While the earth was in this stage of its development its atmosphere was probably rich in complex unstable compounds, including those of carbon, nitrogen and phosphorus, which cannot exist under modern conditions. These materials would have been also held plentifully in solution in the waters of the pools and would have saturated the mud along the sea-shore. The water-logged mud along the sea-shore would have proved a specially suitable

medium for the growth of the first forms of life; for the conditions upon it would have been unusually constant in temperature and moisture, and its soft surface would have formed an excellent support for the primordial jelly. Under such circumstances a complex vaseline-like jelly may have been deposited from the carbon compounds in the atmosphere, and have been combined with various compounds of nitrogen, chlorine and phosphorus. The continued growth of the lumps of this material would have caused their occasional subdivision into smaller masses or globules; and the absorption of various unstable compounds would have endowed the jelly with internal stores of energy, the setting free of which would cause automatic movements in the lumps of jelly. Hence, under the special geographical conditions of the early earth purely chemical processes may have produced masses of carbonaceous material with a chemical composition now found only in organic products, and with the properties of subdivision and movement due to mechanical and physical

forces. This material may be regarded as the immediate ancestor of the first living being, which would have had a very much simpler structure than the cells which are sometimes represented as the most primitive form of life. The simplest living animals are called the Protozoa—the first animals. That name, however, is a misnomer. The Protozoa are comparatively complex organisms. They must have been preceded by a far simpler organism—the Protobion, or "first living being."

This Protobion (*Protos*, first; *bios*, life) was evolved when the primordial jelly was vitalised by the action of one of the reagents known as catalysers.

A catalyser is a chemical agent which will start a reaction between the constituents of a mixture while it itself remains a passive witness of the process, and appears to take no direct part in the operation. An infinitely small portion of a catalyser may be able to maintain a reaction indefinitely without itself being consumed or losing its power, and it may affect any quantity of material. The

gases hydrogen and oxygen, if mixed together, remain as a simple mixture; but if a tiny particle of spongy platinum be dropped into the vessel containing them, the two gases instantly unite with the rapidity and force of an explosion. The platinum is entirely unaltered, and the smallest particle of it will effect the combination of vast volumes of the two gases.

Many apparently mysterious physiological processes, that were at one time regarded as the special functions of life, have now been recognised as the result of the purely physical action of catalysers. That many catalytic reactions are simply physical was explained by Mercer in 1842, by reference to the effect of manganese monoxide on a mixture of oxalic and nitric acids. Oxalic acid ($H_2C_2O_4$, $2H_2O$) destroys nitric acid (HNO_3) by robbing it of part of its oxygen; but a mixture of these acids and water can be made in such proportions that the reduction of nitric action does not take place. The addition then of a particle of manganese monoxide (MnO) restarts the operation, and the nitric

acid is destroyed without any apparent change in the salt of manganese. The explanation is that the manganese monoxide also tends to extract oxygen from the nitric acid in order to pass into the condition of manganese sesquioxide (Mn_2O_3), which contains more oxygen than the monoxide. The nitric acid is therefore reduced by the joint effort of the manganese monoxide and the oxalic acid. But manganese sesquioxide cannot exist in the presence of oxalic acid, and the manganese sesquioxide is therefore instantly again converted to monoxide. It then repeats the process. All the oxygen set free from the nitric acid is therefore acquired by the oxalic acid. The manganese salt acts as a trigger which starts the decomposition of the nitric acid; but as it cannot under the conditions of the experiment combine permanently with the oxygen set free, it remains unaltered, and can continue to maintain the destruction of the nitric acid indefinitely.

The catalysing influence of manganese is not limited to inorganic materials; thus it

has been shown by G. Bertrand[1] that the oxidising action of the diastase known as laccase, which is derived from the banyan tree and also from lucerne, owes its virtue to its manganese, just as the manganese monoxide in the foregoing experiment causes the oxidation of the oxalic acid.

A catalyser is an inorganic and physical agent; and it has the power of acting on indefinite quantities of material. A percussion cap will fire a cartridge or explode a magazine; and the amount of a catalyser has no relation to the amount of material its influence will affect. If the products of a catalytic reaction can carry away with them the minutest particle of the catalyser that has produced them, they are endowed with its creative power.

In all the reactions caused by catalysers energy is set free; a catalyser is like a tap which by a light touch may set in motion thousands of tons of water by allowing it to escape from a cistern. Catalysis never acts

[1] G. Bertrand, "Sur l'intervention du manganèse dans les oxydations provoquées par la laccase," *Compt. Rend. Acad. Sci.*, Paris, vol. cxxiv, 1897, pp. 1032–1035.

like the pump which forces water up into a reservoir.

Hence on the muddy shores of the primeval world the development of life may have been effected in two stages. Firstly, the formation of a complex jelly, mainly composed of carbonaceous compounds which would be formed from the various constituents existing in the primeval atmosphere.

Secondly, the development of a catalyser that would give this jelly the power to break up the various complex unstable compounds available as its food into simpler and more stable materials; and their reduction would endow the jelly with a supply of internal energy which would enable it to maintain a uniform temperature, would create currents in its internal fluids, and some powers of sluggish automatic movement. This internal energy would act as a vital force, and the appearance of the catalyser would have given the chemically precipitated jelly the powers of indefinite increase, subdivision and movement.

The previous statement as to the course of the evolution of Protobion is indefinite, as it has been written without using the names of the varied complex chemical materials that would have been produced during the process. It will therefore be advisable to consider the chemical nature of the materials involved in the evolution of this hypothetical Protobion.

The simplest organic constituents are the carbohydrates, which consist of carbon, hydrogen and oxygen, and are so called because the proportion of hydrogen to oxygen is the same as in water. Thus starch consists of six molecules of carbon (C) united with five of water (H_2O). Its composition is therefore $C_6H_{10}O_5$. Dextrose or grape sugar consists of six molecules of carbon united with six of water; its composition is therefore $C_6H_{12}O_6$. Cane sugar consists of twelve molecules of carbon united with eleven of water; its composition is $C_{12}H_{22}O_{11}$.

The carbohydrates are formed by the combination of carbon dioxide and water, during which some of the oxygen must be removed; thus the formation of starch is

due to the reaction between six molecules of carbon dioxide and five of water during which six molecules of oxygen are set free.

Thus $6CO_2 + 5H_2O = C_6H_{10}O_5 + 6O_2$.

The elimination of the oxygen uses up energy; and the energy required is derived from electric discharges or sunlight. A carbohydrate (formaldehyde) has been formed artificially by the combination of carbon dioxide and water under the influence of an electric discharge. It has long been known that formic acid and formates could be prepared by ordinary chemical processes. Thus Maly, in 1865, produced formic acid from ammonium carbonate, and formates were made by Ballo in 1884 by the reduction of bicarbonates by sodium or potassium. It is true that magnesium and sodium are not at present found as native elements; but it is often maintained that there was no oxygen in the primeval atmosphere. Hence those elements and potassium may then have existed freely on the earth's surface. That the formic acid thus inorganically prepared could be reduced to formaldehyde by the action of the metal magnesium was proved by Fenton

in 1907.[1] He also showed that formaldehyde could be formed directly by the action of magnesium on carbon dioxide in water, without passing through the formic acid stage.

Löb had previously shown that formaldehyde could be formed from carbon dioxide and water under the influence of a quiet electric discharge.

There is no reason why both of these reactions should not have gone on in the primeval atmosphere; and thus a natural inorganic process either under the influence of the electric discharge or of light may have produced ample quantities of carbohydrate.

The carbohydrate (by addition of nitrogen, which is added as a compound with hydrogen) gives rise to the amino-acids which have been described as the "basic substances" of life. These amino-acids are weak acids and have been formed artificially, though they are usually due to organic agencies. The amino-acids are simple in structure; but many of their simple molecules may be interwoven

[1] H. J. H. Fenton, "The Reduction of Carbon Dioxide to Formaldehyde in Aqueous Solution," *Trans. Journ. Chem. Soc.*, vol. xci, 1907, pp. 687–693. This paper contains references to the previous literature.

into a very complex molecule.[1] Amino-acids are converted by this interweaving of the molecules into proteins, which are the main constituents of protoplasm.

The combination of carbon dioxide and water to form carbohydrates requires the presence of both these materials and the presence of some source of energy, such as light or an electric discharge. According to Snyder the first carbohydrate was probably a volcanic product, for he considers that it would only be formed where the carbon dioxide was far more concentrated than it could have been either in the sea or the atmosphere. Volcanoes when in eruption discharge vast quantities of carbon dioxide; and the steam column above a volcano therefore contains concentrated steam and carbon dioxide. The electric flashes that play around the clouds above a volcano could effect the combination of two gases. Hence carbohydrates are probably formed as a result of volcanic action. Nevertheless the

[1] The inorganic condensation of simple into compound molecules has been shown to occur in the case of the members of the acetic acid group by Professor Norman Collie. *Journ. Chem. Soc.*, 1907, pp. 1806–1813.

chemical and physical hustling that takes place during a volcanic eruption is not a very promising condition for the creation of life; and though a considerable concentration of carbon dioxide is doubtless necessary for the quick artificial formation of a carbohydrate in a laboratory, it may probably be formed from a more dilute solution by a very slow reaction under natural conditions.

A sufficient concentration of carbon dioxide for the formation of a carbohydrate may be found around hot mineral springs charged with that gas.

One objection to the volcanic theory of the origin of the carbohydrates is that the temperature would be far too high for the further processes in the evolution of life. It is almost certain that life could not have developed on the earth until the temperature of the climate fell below from 140° to 160° F. At any higher temperature some of the organic constituents would have begun to coagulate. The temperature would be far more suitable on the shores of lagoons or around hot springs than above the crater of an active volcano; and those positions would

be the more suitable since the development could proceed to its later stages in one and the same place.

The intertangling of the molecules of amino-acids into proteins was doubtless a slow, quiet process. Even if the carbohydrates were formed by electric discharges under volcanic conditions, the proteins would not have developed there. The simple primordial jelly probably acquired the more complex composition of the materials allied to protoplasm in some quiet, shallow lagoon, where the waters were rich in carbonaceous compounds and mineral salts, and the sunlight was the source of energy. The conversion of the carbohydrates into proteins most likely occurred in water or in wet mud; for the essential chemical constituents of living matter—its five gases and sulphur, phosphorus, sodium, potassium, calcium and magnesium—are all soluble and are constituents of sea water.

The carbohydrates may have slowly formed in shallow pools under the influence of sunlight; the absorption of nitrogen from ammonia would have converted the carbo-

hydrate to an amino-acid; and the fusion of many of its molecules into one, together with the absorption from the water of minute quantities of salts, converted the acid into protein.

The small quantities of the mineral salts probably acted as inorganic catalysers and gave the Protobion its vital powers. The carbohydrate probably at first would be subdivided by a purely mechanical process, which would be resisted by a skin formed on its surface by the loss of water from the outer layer. As this skin increased in strength the organisms probably acquired the power to subdivide, apart from mere mechanical necessity. This step forward was probably due to the influence of a catalyser containing phosphorus.

Cells subdivide owing to the influence of their nucleus. The most important constituent in this structure is nuclein, of which phosphorus is apparently an essential constituent. Cells deprived of phosphorus live but do not subdivide. Phosphorus is a common constituent of igneous rocks; it occurs in them in the mineral apatite, which

consists mainly of the phosphate of lime. Phosphoric acid must have been dissolved from this mineral, and carried into the pools; and it may there have been used for the formation of the catalyser which endowed Protobion with the power of independent subdivision.

The secret of the development of life is that of the development of this special form of catalyser. Whether we shall ever know its nature is doubtful, for, unfortunately, there is no chance of any contemporary evidence from fossils. Even if the mud on which this Protobion was formed had been preserved, its tissues were so soft that no trace of them can have been preserved. The beds on which Protobion grew have probably long since been destroyed. The development of life may have happened at a time as much before the date of the oldest known fossils as they are earlier than the present day.

Palæontology, the branch of geology which deals with the history of life on the earth, is practically confined to the study of animals and plants with hard parts or solid stems

which can be preserved in the rocks. Interesting evidence is often given by the imprints of soft-bodied animals and leaves in mud, but the interpretation of such impressions is generally difficult and uncertain. The reliable records of former life are mainly those left by animals with skeletons and shells, or plants with woody tissues. The earliest well-preserved remains of animals are found in the rocks of the Cambrian System, and they show that the earth was even then inhabited by highly specialised members of most of the groups of the animal kingdom. There are no vertebrate animals (*i. e.* animals with backbones). The first traces of them have been discovered in the Silurian System. The fossils found in the Cambrian rocks include, however, representatives of nearly all the chief groups. Insects naturally did not make their appearance until later, as they could not appear until land plants were well developed; but of the classes of invertebrates with hard skeletons the great majority were already in existence in Cambrian times. It is therefore quite obvious that life must have ex-

isted on the earth for a prolonged period before Cambrian times. There are among the pre-Cambrian rocks many which might have been expected to preserve any fossils entombed in them; and the evidence of these rocks shows that the physical conditions under which they were laid down were as suitable for the existence of living beings as

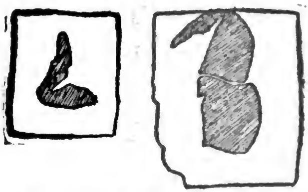


FIG. 38.—Two Appendages of Beltina danai, the chief member of the oldest-known Fauna (after Walcott).

some later rocks which are crowded with fossils.

There is, moreover, certain proof of the existence of life in pre-Cambrian times, but the traces of it are extraordinarily meagre. Some of the grains of phosphate of lime found in the Torridonian Sandstone of Scotland have been shown by Dr. G. J. Hinde to have still recognisable organic structures; and in Montana in the United States there

is a small pre-Cambrian fauna, named after its chief member the Beltina fauna. Beltina (Fig. 38), though the oldest-known well-preserved fossil, is a highly specialised crustacean and must have had a long series of ancestors. It is therefore clear from this and other evidence that in pre-Cambrian times the world was peopled by a large number of highly developed organisms belonging to many different groups and including both animals and vegetables. The rarity of traces is probably due to the fact that they had no hard parts. It seems therefore hopeless to expect that we shall ever trace the history of life far back into pre-Cambrian times, and we may always be dependent on theoretical considerations as to the development of life before the Palæozoic era.[1]

Two explanations have been advanced as to why the pre-Cambrian animals had no skeletons. One is chemical and the other biological. According to the chemical explanation the composition of sea water in

[1] The discovery near Lake Superior of a fossil sponge (named Atikokamia lawsoni) in rocks said to be still older has just been announced by Dr. Walcott. The fossil is also of a specialised lower Palæozoic type.

pre-Cambrian times was such that animals could not secrete shells of carbonate of lime.

The abundant pre-Cambrian limestones show that carbonate of lime was frequently deposited on the floors of these early seas; but it is quite conceivable that this material was not available for the formation of shells. Sea water contains very little carbonate of lime, and the organisms that build their skeletons of this material obtain the lime from the sulphate of lime which is present in greater abundance. The animals excrete carbonate of ammonium, which acts on the sulphate of lime, producing carbonate of lime and sulphate of ammonium. The carbonate of lime thus obtained is used by animals for building their shells. Now if carbonate of ammonium were formed so abundantly in the sea that it was always present in excess, then, as Daly has suggested, it would react upon the sulphate of lime and precipitate it as carbonate of lime. Beds of chemically formed limestone would accumulate upon the sea floor, and there would be none left for the formation of shells. Large quantities of ammonium car-

bonate might be produced by the prolific growth of soft-bodied organisms if their dead bodies were not devoured by carnivorous creatures and were slowly destroyed only by putrefaction and decay.

Some of the sedimentary rocks of the Archæozoic would be very poor in lime, because where animal life was scanty, the ammonium carbonate would not be produced and there would be neither chemical nor organic formation of carbonate of lime.

A biological explanation of the absence of skeletons has been suggested by Dr. J. W. Evans. It also involves the absence from pre-Cambrian seas of any flesh-eating animals. External shells and skeletons are usually developed as a defence against the carnivorous animals; while internal skeletons give their owners powers of rapid movement either for escape from their enemies or for the pursuit and capture of their prey. The earliest specialised animals were doubtless vegetarian. They probably lived on the microscopic plant life floating in the sea. The adoption of a carnivorous diet must have been a subsequent change. Accord-

ingly when all animals lived on vegetable food none of them had any need of hard shells, spines, armour plate or other defensive structures. Dr. Evans has made the ingenious suggestion that shortly before Cambrian times one species of animal became carnivorous. It would have found itself surrounded by an inexhaustible supply of unprotected food and its numbers would have multiplied rapidly, and it would soon have become dominant form of life.

Under pressure many different animals were forced by natural selection at about the same time to develop shells. With the exceptions of animals of special habits or perhaps repulsive taste only those survived that made this change. Thus there was a simultaneous development of shells in many different classes of organisms, and they were all able at the same period to leave their first records on the sands of time.

This theory has one defect. Many hard parts are of use as mechanical supports and not for defence. Thus soft-bodied animals, as in some corals, live in an exposed layer around an axial skeleton. Branching skele-

tons are often useful as they prevent the colonies being rolled about by waves or damaged in the surf, or as they raise the soft parts above the muddy or sandy sea bottom into purer water, or as they increase the area from which oxygen or other food can be collected. Such adaptations to the physical forces that acted in the pre-Cambrian seas would have been as useful then as in later times. Moreover, burrowing animals such as worms doubtless lived in pre-Cambrian times; but there are very few traces of them, and they first appear in any abundance with other animals at the beginning of the Cambrian.

It is clear that, from whatever cause, animals first began to develop shells and calcareous supports at about the beginning of Cambrian times.

For an explanation of the origin of Life we may always be dependent on the possible methods suggested by physiologists. But those theoretical methods, it is unfortunately only too probable, we shall never be able to test by the contemporary records found in rocks.

July 1912.

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1st, the centre of gravity being eccentric in position;

2nd, the shape not being a sphere, but an ellipsoid with three unequal axes, like an egg flattened on two sides;

3rd, different areas having different densities, the denser parts tend to fly outward in consequence of the rotation, and thus the surface becomes furrowed by the alternation of areas of elevation and depression.

Prof. Love shows that on such a body the arrangement of the continental elevations and oceanic depressions would

approximately correspond to those which exist upon the earth. He has clearly explained the theory in his Presidential Address to the Physical Section of the British Association at Leicester in 1907. The results correspond largely with those of the tetrahedral theory, which, however, offers a simpler, and perhaps more probable, explanation of the distribution of the elevations and depressions. His full memoir, entitled "The Gravitational Stability of the Earth," is published in the *Philosophical Transactions of the Royal Society*, vol. 207, 1908, pp. 171–241.

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